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ABSTRACT

This technical specialty course is one of thirty-five courses designed for use by two-year postsecondary institutions in five nuclear technician curriculum areas: (1) radiation protection technician, (2) nuclear instrumentation and control technician, (3) nuclear materials processing technician, (4) nuclear quality-assurance/quality-control technician, and (5) nuclear reactor (plant) operator trainee. This course, Welding Inspection, contains ten modules: Welding Fundamentals and Processes; Shielded Metal Arc and Oxyacetylene Welding; Tungsten Inert Gas, Metal Inert Gas, and Submerged Arc Welding; Weld Joint Verification; Qualifications; Process Controls; Acceptance Inspection; Filler Materials Control; Weld Repair Control; and Records. Each module follows a typical format including the following sections: introduction, module prerequisites, objectives, subject matter, exercises, materials, procedures, data tables, reference materials, and tests. (A master index and suggested program planning guides are also available--see CE 026 856 and CE 026 639-643.) (LRA)

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Nuclear Technology Series

COURSE 28

WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH
AND DEVELOPMENT, INC.

4800 LAKEWOOD DRIVE
WACO, TEXAS 76710

CE 026 668

U.S. DEPARTMENT OF HEALTH,
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PREFACE

ABOUT NUCLEAR TECHNOLOGY MODULES

The modules – developed for use in two-year postsecondary technical institutions to prepare technicians for employment – are useful in industry for updating employees in company-sponsored training, and as laboratory texts in engineering schools. The principles, techniques and skills taught in the modules, based on tasks that nuclear technicians perform, were obtained from a nationwide advisory committee of employers of nuclear technicians. Each module was written by a working technical expert/experienced writer team and tested with students.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Module Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Materials, which identify the equipment required to complete the laboratory procedure.

Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

Reference Materials, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of the prestated objectives.

A helpful Index has been added at the end of each course.

The materials contained herein were developed pursuant to a contract with the Office of Education, U.S. Department of Health, Education and Welfare: Contract No. 300780582. Contractors undertaking such projects under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official Office of Education position or policy.

The Nuclear Technology Series consists of five curricula:

- Nuclear Reactor (Plant) Operator Trainee.
- Radiation Protection Technician.
- Nuclear Materials Processing Technician.
- Nuclear Quality-Assurance/Quality-Control Technician.
- Nuclear Instrumentation and Control Technician.

The completed Nuclear Technology Series consists of the following 35 technical specialty courses:

- Radiation Physics.
- Radiation Protection I.
- Principles of Process Instrumentation.
- Heat Transfer and Fluid Flow.
- Introduction to Nuclear Systems.
- Instrumentation and Control of Reactors and Plant Systems.
- Reactor Operations.
- Reactor Safety.
- Reactor Auxiliary Systems.
- Power Plant Systems.
- Radiation Detection and Measurement.
- Reactor Physics.
- Power Plant Chemistry.
- Introduction to Quality Assurance/Quality Control.
- Metallurgy and Metals Properties.
- Mechanical Component Characteristics and Specifications.
- Radiation Protection II.
- Radiological Emergencies.
- Radiation Shielding.
- Radiation Monitoring Techniques (Radiochemical).
- Radioactive Materials Disposal and Management.
- Advanced Radionuclide Analysis.
- Nuclear Chemical Processes.
- Nuclear Systems and Safety.
- Radioactive Material Handling Techniques.
- Nondestructive Examination (NDE) Techniques I.
- Metrology.
- Welding Inspection.
- Civil/Structural Inspection.
- Mechanical Inspection.
- Quality-Assurance Practices.
- Nondestructive Examination (NDE) Techniques II.
- Control Systems I.
- Control Systems II.
- Power Plant Electrical Systems and Components.

Availability: Instructional modules are available individually or by courses from:

Center for Occupational Research and Development
4800 Lakewood Drive, Suite 5
Waco, Texas 76710
Telephone (817) 772-8756

Printed:

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NUCLEAR TECHNOLOGY

MODULE 28-1

WELDING FUNDAMENTALS AND PROCESSES

COURSE 28 WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

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COURSE MODULES

COURSE 28 WELDING INSPECTION

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INTRODUCTION

Metallic parts can be joined by mechanical connections, such as bolting, threading, and clamping, or by welding. Mechanical connections permit relatively easy disconnection for inspection, repair, or replacement but are not always suitable for the service or environment of the parts. Mechanical connections of parts containing pressurized fluid tend to leak. Space restrictions can greatly complicate the design of mechanical connections. High joint strength with high joint flexibility is difficult to obtain with mechanical connections. For these reasons and others, many metallic parts are joined by welding to obtain high strength, flexible, leak-tight and compact connections.

Welding of parts encompasses both joining of components and individual pieces of components. Chances are that the chairs, desks, and tables you are using contain pieces joined by welding. A glance at such welds quickly shows that shape and contour of weldments can blend with the desired shape and contour of the furniture. The history of welding shows advances aimed at speed, repeatability, and freedom from defects. A number of different welding processes have been developed which make it possible to choose the best welding process for any of a broad spectrum of applications. Each welding process has its unique advantages and techniques; the welding engineer reviews the techniques and advantages in order to select the welding process that is best for a specific application. The nuclear QA/AC technician, while normally not expert enough to be a qualified welder, needs to understand the fundamental characteristics of welding, the unique features of specific welding processes, and the effects on weld quality caused by the departure from qualified welding procedures. This understanding is necessary to permit correct inspection of welding operations and proper application of inspection results.

This module describes the role and responsibilities of the QA/QC technician in welding inspections. It also discusses fundamental aspects of welding in order to provide the student/trainee with an adequate base level of knowledge. Knowledge of these fundamental aspects will equip the student/trainee to understand succeeding modules in this course and will familiarize him or her with many of the concepts and terms that are used in making a welding inspection.

The concepts and terms explained in this module are used in later modules of this course without additional description. Thus, it is important for the student to study the concepts and terms carefully and to be sure that he or she understands how they are used before going on to the next module.

This module first describes general responsibilities of the QA/QC technician in welding inspection, fundamentals of welding, welding techniques, common types of defects and heat treatment. It then presents a general overview of the five welding processes most frequently used in nuclear power plant welding.

MODULE PREREQUISITES

None.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Describe the general responsibilities of the QA/QC technician in welding inspection.
2. List five basic types of weld joints.
3. List one or more factors that affect the choice of joint type.
4. Describe the following weld joint features, using standard terminology, base metal, unaffected base metal, root gap, weld-end face, included angle, reinforcement, toe, weld metal, fusion zone, heat affected zone.
5. Discuss the electric arc heat source and the fuel flame heat source as they relate to the welding operation.
6. List two or more causes of distortion of the weld joint and describe four basic measures that control distortion.
7. State the purpose of filler material in a weld and list four basic types of filler material.
8. State the purpose of shielding during the welding operation.
9. List and describe seven welding techniques that are common to all welding processes.
10. List defects that are common to all welding processes. Describe the appearance of each type of defect and discuss its probable cause.
11. Discuss the effects of preheating the base metals, controlling interpass temperature, and post weld heat treatment on the weld.
12. Given each of the five welding processes most frequently used in nuclear power plants - oxyacetylene welding, tungsten inert gas welding,

shielded metal arc welding, metal inert gas welding, and submerged arc welding - describe the following aspects:

  - apparatus need
  - applications
  - method of shielding
  - type of heat source
  - type of filler material

13. Given a weld specimen, identify the welding technique used, locate defects through visual examination, state probable causes of any defects found.
14. Identify by observation, the following aspects: the welding operation, the welding process, the welding technique, the type of shielding, the type of filler material, heat source, apparatus, and visible defects in the finished weld.

SUBJECT MATTER

GENERAL RESPONSIBILITIES OF THE QA/QC TECHNICIAN IN WELDING INSPECTION

Written procedures govern most aspects of the welding operation. These procedures specify such things as welder qualification, welding equipment and set-up, the welding process, heat treatment, and the types and sizes of unacceptable defects. In some instances, the written procedures also specify the welding technique. The purpose of these procedures are to prevent weld failure and to assure a good quality weld. The QA/QC technician must see that the written procedures for welding operations are applied and that the finished weld meets stated acceptance criteria.

Specific duties of a QA/QC technician vary, depending on the type of facility and on the requirements of the employer. In general, however, the QA/QC technician's duties in welding fall into three categories; verification, monitoring, and inspection. The QA/QC technician verifies that the welder is qualified and the welder has followed the written procedure for the set-up of equipment and for the use of parts. The QA/QC technician monitors the welding process while it is in progress to ensure that equipment and parts are used as the procedure specifies. After the welding operation has been completed, the QA/QC technician visually inspects the finished welds for unacceptable defects and for the specified amount of filler metal buildup. If work specifications require it, the QA/QC inspector also conducts and/or monitors nondestructive tests to detect defects. If unacceptable defects are found, the QA/QC technician may be responsible for monitoring the repair operation to ensure that repair procedures are followed and for reinspecting the repaired weld. Finally, the QA/QC technician completes written reports on the disposition of the weld.

Welding operations and associated inspections are closely intertwined, such that the efforts of three disciplines (welding engineering, welders, and QA/QC) play vital roles in assuring that sound welds are made. This course is primarily geared toward the role of the QA/QC technician but includes ample information on the roles of welding engineering and welders to permit an understanding of the bases for the QA/QC role and its relationship to the other disciplines.

FUNDAMENTALS OF WELDING

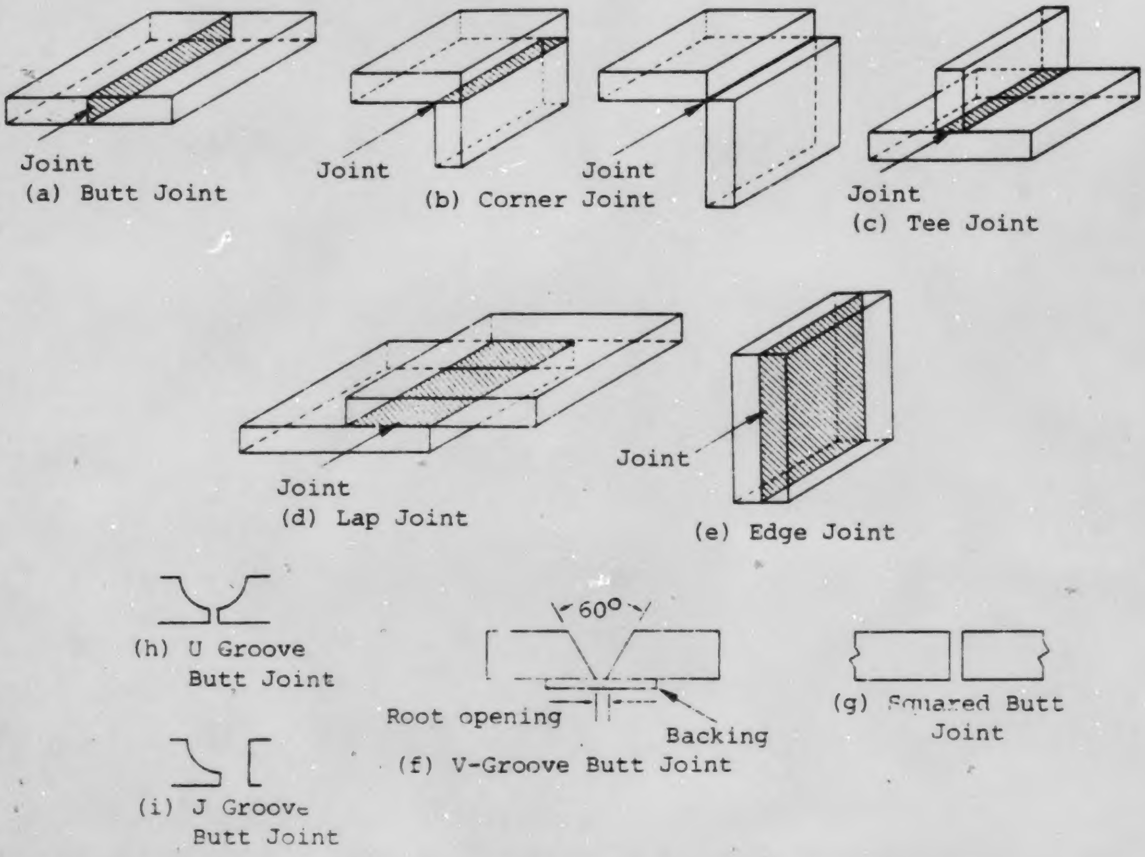
Welding is a process of joining metals by momentarily melting the adjoining surfaces of metallic parts, permitting the molten metal to coalesce, and then resolidifying the metals to form a bond between metallic parts. Anytime welding is done, written procedures govern the welding operation. A welding engineer writes procedures that specify the welding process to be used and as necessary describe specific welding techniques. These procedures must be consistent with and take into account, all applicable codes and regulations. The quality assurance engineer reviews all of the welding procedures and directs the quality assurance/quality control (QA/QC) technician to monitor the welding operation for compliance with these welding procedures. In order to assure compliance with welding procedures, the QA/QC technician must have a good grasp of the fundamentals of welding.

There are six fundamentals involved in obtaining a successful weld: the weld joint, heat source, distortion control, filler material, shielding, and appropriate welding techniques. This module discusses each fundamental as it applies to any welding process.

WELD JOINTS

Configuration

The configuration of a weld joint directly influences the ultimate strength of the joint, the ease of welding and the probability of defect-free weldments. There are five basic types of joints: butt, corner, tee, lap and edge. Weld joints may also be squared or grooved. Figure 28-1-1 Fundamental Weld Joints illustrates these types.



(a) Butt Joint

(b) Corner Joint

(c) Tee Joint

(d) Lap Joint

(e) Edge Joint

(h) U Groove Butt Joint

(f) V-Groove Butt Joint

(g) Squared Butt Joint

(i) J Groove Butt Joint

Figure 28-1-1 Fundamental Weld Joints

Considerations in Choosing Joint Type

The designer, normally in concert with the welding engineer, selects the basic type of joint to be used. Governing factors include space restrictions, shape envelope, strength requirements, and the stresses to which the joint will be subjected in service. In general, the butt joint is used where highest stresses will be applied. This joint provides uniform contour and, thereby, equalizes the stresses throughout the joint. The corner and tee joint cannot withstand as much stress as the butt joint but they are still high-strength joints. These two joints facilitate changes in space envelope where stresses do not dictate that a butt joint be used. The lap joint is used in low stress applications or where there is moderate stress only in the direction parallel to the surfaces of the overlapping plates. The edge joint is used in low stress applications. Most nuclear welding employs butt, corner, and tee joints. Lap joints, and less frequently edge joints, are sometimes used in building construction.

Another important factor with respect to the strength of a weld joint is the extent of fusion of welding. If the entire area and volume of the weld joint is fused by welding, the weldment is a full penetration weld. Conversely, fusion of only a portion of the area and volume of the joint gives a partial penetration weld. Obviously, a full penetration weld has the higher strength. To facilitate full penetration, joints are grooved as shown in Figure 28-1-1. The groove permits access by the welding heat source to the root opening. Given such access, the complete joint is fused by a series of passes by the welding heat source. The squared joint shown in Figure 28-1-1 doesn't provide direct access to the root opening.

It would not permit full penetration welds except for thin materials where the entire joint can be fused in one pass of the welding heat source. The U and J joints as shown in Figure 28-1-1 permit as good penetration as the V joint, but with less weld metal and time, especially in thick material.

Terms Used to Describe Joint Features

Standard terminology is used in describing weld joint features. Most frequently used terms are defined as follows and illustrated in Figure 28-1-2.

- Base Metal - the metals to be joined by welding
- Unaffected Base Metal - the base metal whose chemistry and physical properties are unaffected by the welding process
- Root Gap - the distance between the surfaces to be welded measured at the bottom of the weld joint
- Weld End Face - the surface area of the surfaces to be joined by welding
- Included Angle - the angle formed by the perpendicular centerline of the weld joint and the weld end face
- Reinforcement - weld metal thickness in excess of nominal base material thickness specified for the weld joint
- Toe - the interface of either side of the weld metal with the base metal along the longitudinal surfaces of the weld joint
- Weld Metal - the volume of metal whose chemistry and physical properties are those of the mixture of added filler material and base metal

Figure 28-1-2 illustrates the joint features described in this module.

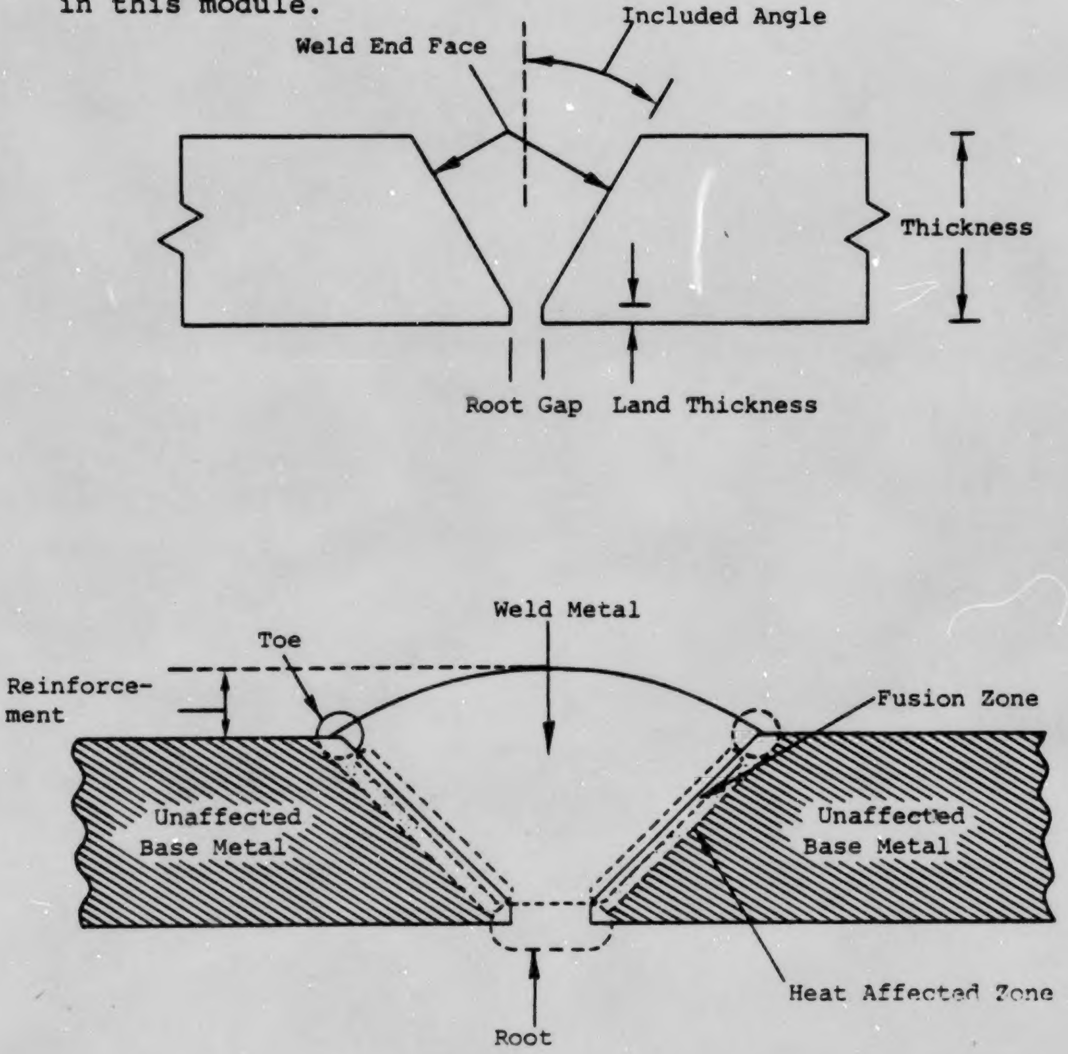

Included Angle
Weld End Face
Thickness
Root Gap
Land Thickness
Weld Metal
Toe
Reinforcement
Fusion Zone
Unaffected Base Metal
Unaffected Base Metal
Heat Affected Zone
Root

Figure 28-1-2 Weld Joint Features

- Fusion Zone - the volume of base metal and filler material in the vicinity of the weld end faces which melts and resolidifies during the weld process
- Heat Affected Zone - the volume of base metal which did not melt, but whose physical properties were altered by the heat of welding
- Root - the volume of base metal and filler material melted and resolidified by the first welding pass.

HEAT SOURCES

General

As heat is applied, it is conducted throughout the metals to be joined. Since the parts are metallic, rapid loss of heat occurs, particularly when massive parts are to be welded. The heat source, therefore, must input heat very rapidly to melt only the weld end faces without bringing the entire mass to the melting point of the base materials. The QA/QC technician verifies that the heat source specified in the welding procedures is used. Fuel flame and electric arc are the two basic types of heat sources used for fusion welding.

Fuel Flame Heat Source

Fuel flame heat source consists of oxygen and a combustible fuel. Due to its high heat generation, acetylene is frequently used as the fuel. The oxyacetylene flame consists of oxygen and acetylene and is applied directly to the weld end faces until melting occurs. Controlling movement of the flame along the weld joint permits melting new areas and resolidification of previously melted areas. This type of fuel flame heat is shown in Figure 28-1-3.

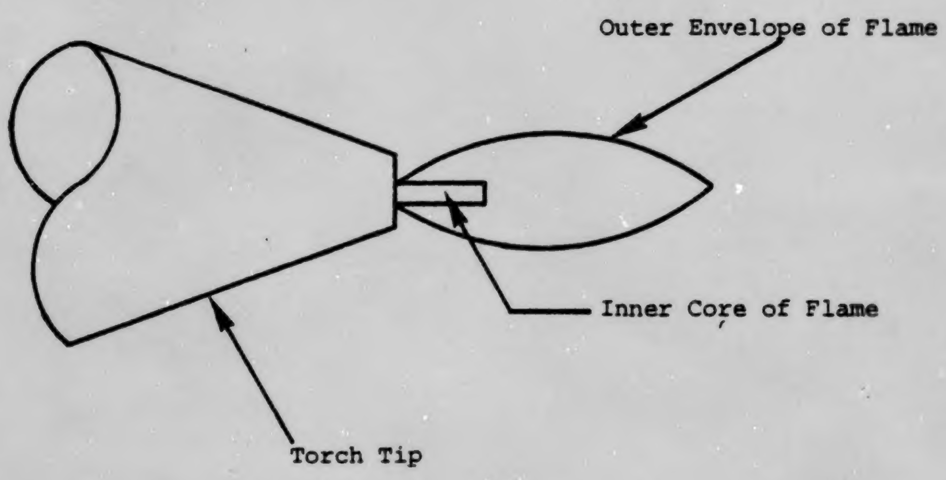


Figure 28-1-3 Fuel Flame Heat Source

Electric Arc Heat Source

Electric arc heat source uses the power generated by electrical current flow through a resistance. This power in watts can be calculated by formula 28-1-1 which is derived as follows:

$E = IR$, then, (Ohm's law) Formula 28-1-1
$W = EI$, then, (based on Ohm's law)
$W = IRI = I^2R$ (substituting IR for E)

Where: E = Voltage
I = Current

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R = Resistance

W = Watts

Notice that the power in watts increases rapidly as the current is increased. This happens because power is proportional to the square of current. Since this power in an electric arc exists as light and primarily heat, large heat inputs can be derived from moderate current values, e.g., 20 to 500 amperes of current. (Amperes is a measure of current flow where one ampere is equal to one coulomb of charge moving past a given point in one second. One coulomb is the charge represented by 6.3×10^{18} electrons.)

In an electric arc heat source, the arc path presents a high resistance to current flow, as compared to the resistance of base metals. Therefore, practically all of the heat generated by the current flow is dissipated in the arc. The fundamental features of an electric arc are shown in Figure 28-1-4 below.

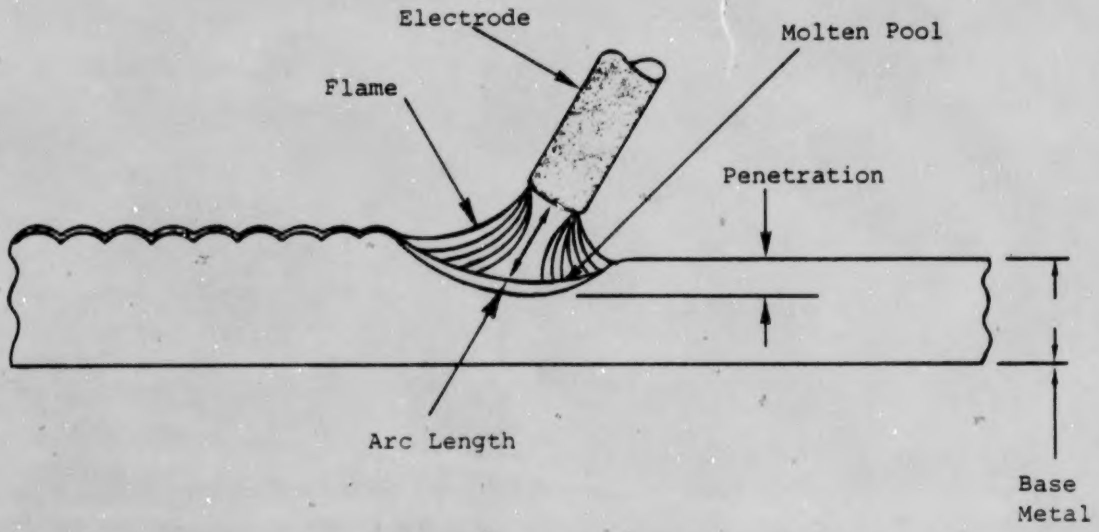


Figure 28-1-4 Electric Arc Heat Source

DISTORTION CONTROL

General

Distortion of the weld joint can lead to weld failure. Therefore, the weld engineer in his or her design of welding processes, is careful to specify or describe fixturing that minimizes distortion. The QA/QC technician inspects the placement of fixturing to determine whether specified distortion control measures have been applied. To carry out this task, the QA/QC technician must recognize possible causes of distortion and must be familiar with distortion control.

Causes of Distortion

The atoms of metals arrange themselves in definite patterns (crystals) as metals solidify during welding. The size of these crystals varies considerably, depending on such factors as type of metal and the cooling rate through the temperature at which solidification occurs. The welding process can result in crystals of different sizes from those originally in the base metal and, therefore, cause distortion of the weld joint. Another cause of distortion of the weld joint is the temperature difference (gradient) from the weld end faces to the surrounding base metal. This temperature gradient causes internal stresses which distort the weld joint. Also the molten weld metal shrinks considerably in solidification and cooling, possibly resulting in residual stress and distortion.

Distortion Control Measures

Distortion of the weld joint is undesirable because it may lead to weld failure at some point in time due to non-uniform application of stresses. Also, distortion makes it difficult, if not impossible, to comply with dimensional requirements and, if the joint is in a flow path, it may restrict flow. Distortion can be minimized by the application of control measures in the welding process. Distortion can be controlled and minimized by the following measures:

- Selection of the correct base metal - Certain metallic alloys solidify with only one crystal size possible.
- Physical restraint - Clamps and fixtures are used to physically restrain the parts to be welded.
- Proper joint design - Proper joint design permits easier control of the heating and cooling rates during the welding process.
- Proper welding techniques - Heating rates are selected which result in proper welding (uniform fusion), while minimizing distortion due to internal thermal stresses. Further, distortion is minimized by preferential welding, i.e., alternately welding different areas of the weld joint to avoid excessive localized internal stresses.

FILLER MATERIAL

General

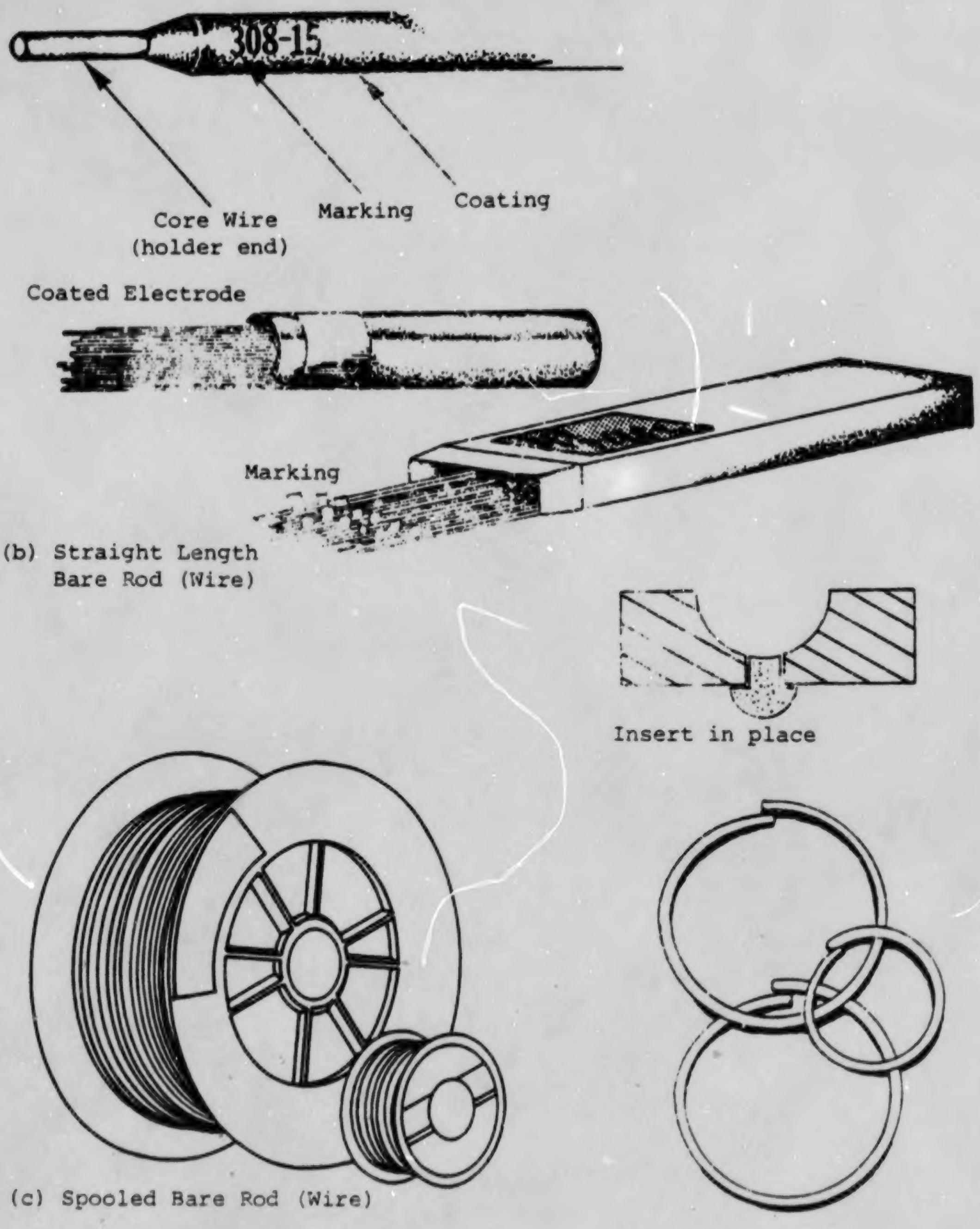
If the weld metal is formed solely by melting the weld end faces, insufficient material is available to "fill up" the joint, (See Figure 28-1-1). Unless extra metal is added, the resulting weld will be thinner than the base material thickness.

Extra metal (filler material) can be preplaced in the joint and melted by welding or it can be fed into the heat source such that it is added continuously to the localized area being melted. Other than consumable inserts, preplaced filler material is normally not used in the nuclear power applications because of the difficulty in assuring that all such metal has been melted and thereby fused uniformly. Further, preplaced filler material requires more heat input and thereby increases risk of distortion.

The filler material for a weld is specified in the welding procedures. Before a weld is made, the QA/QC technician inspects the filler material to be sure that it is the filler material that is specified in the welding procedures.

Types of Filler Materials

There are four basic types of filler material used in nuclear power plant applications. They are: coated electrode, straight length bare rod, spooled bare rod, and consumable inserts. The straight length bare rod is normally used with the oxyacetylene flame welding process. Any of the four types of filler materials may be used in the electric arc welding process. Figure 28-1-5 illustrates the four basic types of filler materials.


308-15
Core Wire (holder end)
Marking
Coating
Marking
Insert in place

Coated Electrode

(b) Straight Length Bare Rod (Wire)

(c) Spooled Bare Rod (Wire)

(d) Consumable Inserts

Figure 28-1-5 Types of Filler Materials

SHIELDING

Each welding process requires some means of shielding the hot weld metal from the atmosphere in order to prevent corrosion during welding. The earth's atmosphere is composed of about 80% nitrogen and 20% oxygen. Most metals have a strong tendency to combine with oxygen and a lesser tendency to combine with nitrogen. This tendency grows as the temperature of the metals increases, such as during welding. The resulting oxides and nitrides are weak and brittle and represent serious problems to the soundness of a welded joint. The oxides and nitrides may become entrapped within the weld bead or may form surface films which preclude complete fusion as the next welding pass occurs. Nitrogen and hydrogen will also dissolve in certain metals (aluminum, low alloy steels and zirconium for examples) and thus introduce internal stresses which cause cracking. A simple means of removing oxygen, nitrogen and hydrogen from the vicinity of the weld joint is to displace these elements with a substance which is not harmful to the weld. The displacement substance is called shield or shielding and is discussed later in this module.

The welding procedure specifies shielding material. Right before and/or during a welding operation, the QA/QC technician inspects the shielding material to be sure that the specified material is used.

WELDING TECHNIQUES

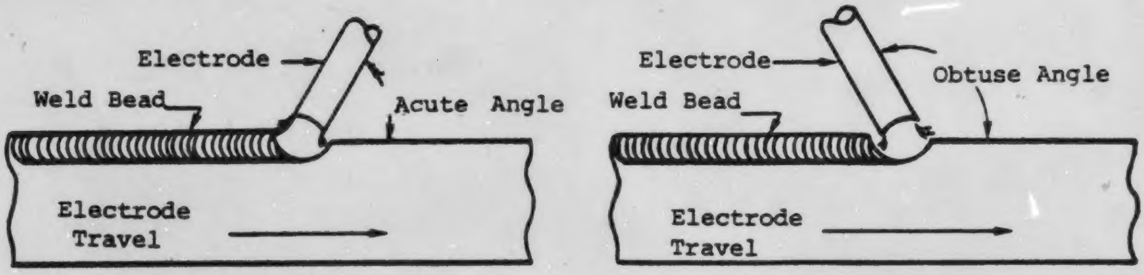
General

The same welding technique is not used for every welding process or for every weld joint. Rather, the welding technique that will produce the best results, given a particular welding process or joint configuration, is selected. Usually, the welder selects the technique, but sometimes the welding technique is specified in the welding procedure. If the technique is specified in the welding procedure, the QA/QC technician monitors the welding process to ensure that the specified technique is used.

While each welding process involves some unique techniques, many techniques are common to all of the welding processes. Seven common techniques are examined in this module: forehand and backhand; single pass and multipass; weave and stringer bead; positional; interpass cleaning; reverse side welding techniques; and vertical progression.

Forehand and Backhand Techniques

The backhand and forehand techniques are used to shape the molten weld puddle to obtain uniform fusion with little irregularity in the thickness of the resultant weld bead. Shaping of the puddle is possible because the flame or electric arc exerts a force on the molten weld puddle which "pushes" the puddle in the direction of the force. The effect of this force is controlled by adjusting the angle of the flame or electrode in relation to the work piece. As shown in Figure 28-1-6, this angle may be acute (less than 90°) as in the backhand technique or obtuse (greater than 90° and less than 180°) as in the forehand technique. The forehand technique gives easiest control of the puddle when using the oxyacetylene heat source. The backhand technique is normally best for the electrical arc welding process. It permits a smaller included angle (narrower) groove, saving filler, and usually yields a higher quality weld.



(a) Backhand Technique (b) Forehand Technique

Figure 28-1-6 Backhand and Forehand Welding Techniques

Single Pass and Multipass Technique

The single pass technique completes the weldment with one traversal (pass) of the heat source while the multipass technique uses two or more passes of the heat source. (The discussion on distortion control noted the importance of controlling the rate of heat input and resulting thermal gradient from the weld joint to surrounding base metal.) The amount of heat input required is directly proportional to the volume of metal to be melted with a single pass of the heat source.

If the entire weld joint is to be welded in one pass of the heat source, a large heating rate is necessary, particularly as the thickness of the joint increases. Therefore, a single pass technique can be used for relatively thin weld joints but is unsuitable for thicker joints. The multipass technique permits low rates of heating because less volume of metal is melted per pass.

Weaver and Stringer Bead Techniques

Welding naturally progresses along the length of the weld joint (longitudinal axis of the joint). However, the heat source may also be moved tranversely at the same time it is moved in the longitudinal direction. The weave bead technique employs both movements such that the complete width of the joint is welded as the length is welded. The weave bead technique requires fewer steps for bead cleaning because there are fewer weld beads. Also, it requires fewer total passes of the heat source to complete a multi-pass weld. It is very good for vertical, single pass welds. A disadvantage of the weave bead technique is the higher probability of incomplete fusion because the molten weld puddle is being pushed in several directions and the fusion zone alternately changes from weld end face to weld bead.

The stringer bead technique uses little or no weaving in the traverse direction. Since the molten weld metal is being pushed in essentially one direction, uniform fusion is more easily assured. More cleaning steps are needed, however, because more beads are needed to complete the weld. These techniques are shown in Figure 28-1-7.

Positional Techniques

The welder may be able to position parts to be welded or the parts may be immobile. Since various physical positions of the weld joint give different degrees of difficulty in making a sound weld, the welding procedure and the welder's techniques must be tailored for the position to be used. Because gravity is always attracting the molten weld puddle, the most favorable positions are those which physically limit the flow of molten metal. There are four basic welding positions: flat, horizontal, overhead, and vertical. Each position is shown in Figure 28-1-8, which

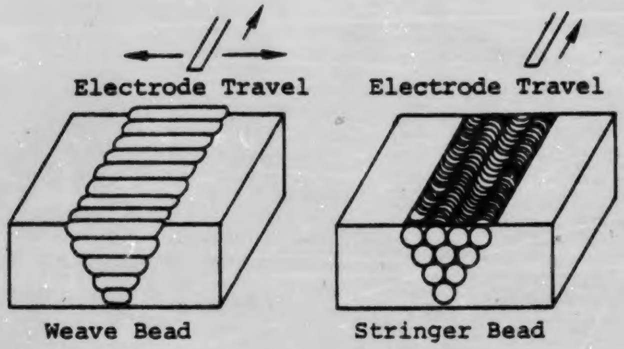


Figure 28-1-7 Bead Techniques

is taken from Section IX ASME Boiler and Pressure Vessel Code.

- Flat Position presents least difficulty for controlling the molten weld puddle. The force of the fuel flame or electric arc controls the shape and flow of the molten weld puddle relatively easily and thus offers high assurance of uniform fusion. Oftentimes, components are rotated by positioners to maintain the flat position at the point of welding. Welds are in the flat position if their longitudinal axis is from 0° to 15° from the horizontal plane while their perpendicular axis is within 30° either side of vertical.
- In the Horizontal Position, it is more difficult to control the molten weld puddle because the weld joint geometry permits flow of the puddle due to gravitational forces. A little more precision in controlling the angle of the heat source is needed to counter the gravitational force and thus assure uniform fusion. Welds are in the horizontal position when their

longitudinal axis is 0° to 15° from the horizontal plane while their perpendicular axis is between 30° and 100° either side of vertical.

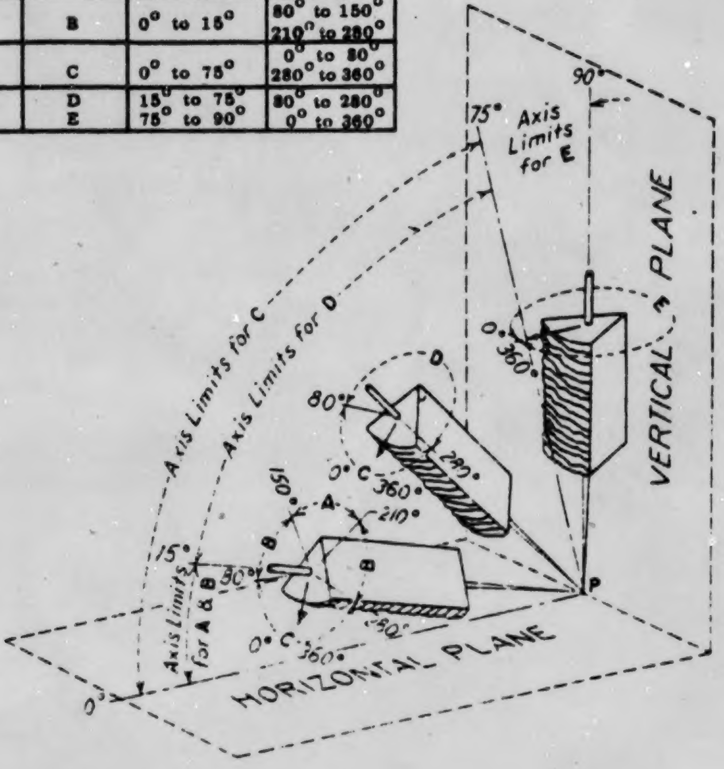
- Overhead Position and Vertical Position have the highest degree of difficulty for making a sound weld. In the overhead position, the molten weld puddle is likely to drip from the weld joint. Molten weld metal in the vertical position is likely to run down the weld end faces. In addition to controlling the angle of the heat source, it is usually necessary to lower the heating rate which reduces the mass (weight) of metal that is molten at any given time. Therefore, the overhead and vertical positions are not only difficult to weld properly but also more time consuming because each welding pass fuses less volume of metal than can be fused in the flat or horizontal positions. Welds are in the overhead position when their longitudinal axis is 0° to 75° from the horizontal plane while their perpendicular axis is between 100° and 260° from vertical. Welds are vertical under two conditions: (1) Longitudinal axis is 15° to 75° from the horizontal plane while perpendicular axis is within 100° either side of vertical, or (2) Longitudinal axis is 75° to 90° from the horizontal plane regardless of the position of the perpendicular axis.

Vertical Progression Technique

Welding progression (i.e., direction of travel of heat source along the longitudinal weld axis) has about the same degree of difficulty for controlling the molten weld puddle

TABULATION OF POSITIONS OF WELDS

Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 280°
Overhead	C	0° to 75°	0° to 80° 280° to 360°
Vertical	D E	15° to 75° 75° to 90°	80° to 280° 0° to 360°


90°
75° Axis Limits for E
VERTICAL PLANE
Axis Limits for C
Axis Limits for D
0° 360°
D
80°
280°
0° C 360°
150°
A
210°
B
15°
80°
B
Axis Limits for A & B
0° C 360°
280°
P
HORIZONTAL PLANE
0°

NOTE: The horizontal reference plane is taken to lie always below the weld under consideration.

Inclination of axis is measured from the horizontal reference plane toward the vertical.

Angle of rotation of face is measured from a line perpendicular to the axis of the weld and lying in a vertical plane containing this axis. The reference position (0 deg.) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. The angle of rotation of the face of weld is measured in a clockwise direction from this reference position (0 deg.) when looking at point P.

Figure 28-1-8 Welding Positions

in the flat, horizontal, and overhead positions. However, for the vertical position, different angles of the heat source are needed between progressing up the joint and progressing down the joint. For this reason, vertical progression (up or down) is often considered an essential variable which requires specific tests to assure that the progression to be used will result in a sound weld.

Interpass Cleaning Technique

After each pass of the heat source in most welding processes, the weld bead needs to be cleaned in order to prevent entrapping foreign materials by the next pass. Cleaning methods include: chipping with a slag pick, wire brushing (manual and powered), and grinding. Since different degrees of cleanliness are obtained with these cleaning methods, the method used during qualification of the welding procedure must be used during production welding.

Reverse Side Welding Technique

It is typically more difficult to obtain a quality weld in the root than in the remainder of the weld joint. If the weld joint is welded only from one side, more stringent controls are needed for such factors as root gap dimensions, backing, and heating rate for the root pass in order to avoid defects in the root. Even with stringent controls, subsequent inspection may find defects in the root and the entire weld, for the weld volume where the defects are located, must be removed down to the root and then rewelded. This problem can be avoided if space is available to weld both sides of the weld joint. After welding one side, the backside of the deposited weld metal is gouged out, which removes the original root area and any defects which may have existed.

Back gouging may be accomplished by chipping or grinding, or arc gouging, and it is performed in a manner which forms the dimensions of the backside that are suitable for welding. Since substantially different techniques are employed for welding one side, as opposed to welding both sides, production welding must use the technique that has been tested and proven satisfactory on a weld mockup.

WELD DEFECTS

Types of Defects

Defects may occur in the welded joint when there is inadequate control of any of the six fundamentals discussed in this module. Certain defects are acceptable, depending on the size of the defect and the intended use of the welded joint. The designer of the weld joint stipulates the types of defects and the size of defects that are unacceptable. The QA/QC technician inspects the completed weld to determine whether any defects present are acceptable or unacceptable.

Each welding process has characteristic defects associated with it. However, there are many defects that are common to all welding processes. This module describes the defects that are common to all welding processes. They are: incomplete fusion; cracking; inclusions; porosity; undercutting; root concavity; root convexity; burn through or melt through; and underbead cracking.

Incomplete Fusion

Incomplete fusion is the failure to melt together the filler metal and base metal or the failure to melt one filler metal bead to another filler metal bead. Incomplete fusion is most likely to occur along the weld end faces and between beads of multipass welding. Incomplete fusion is caused by insufficient heating rate, excessive weaving, improper control of angle of heat source or insufficient accessibility by the heat source for complete melting.

Cracking

Cracking is separation in the normal bond among the atoms of the crystalline structure. Cracks may appear anywhere in the weld joint where melting and resolidification have occurred. They are caused by excessive heating or cooling rates and, when more than one type of metal is used in the weld joint, by differences in expansion coefficients between the metals used. It may also be caused by hydrogen embrittlement due to improper welding, heat treatment or plating technique; or improper control of delta ferrite in stainless steel. Delta ferrite is a form of iron which is included in stainless steel alloy welding filler metals for the purpose of increasing the resistance of the deposited metal to cracking.

Inclusion

Inclusion is entrapment of foreign material in the weld metal. Inclusions may occur throughout the weld joint and are caused by inadequate interpass cleaning, excessively rapid solidification of the molten weld puddle (caused by combination of low heating rate and fast travel speed of heating source), or inability of the heat source to "float out" inaccessible foreign material. Oxide inclusions can occur when shielding is lost.

Porosity

Porosity refers to cavities in the weld metal. Porosity is caused by entrapment of gases in the weld metal as solidification occurs. Porosity can occur in any portion of the weld metal. It is caused by excessively rapid cooling and solidification of the molten weld puddle.

Undercutting

Undercutting is an intermittent or continuous depression or groove along the toe or root of the weld left unfilled by weld metal. Undercut is caused by excessive heating rates, insufficient addition of filler metal, or by insufficient number of weld passes.

Root Concavity

Root concavity is a depression in the root surface of the welded joint. It may be caused by gravity or improper combination of heating rate and travel speed of the heat source.

Root Convexity

Root convexity is excessive reinforcement at the root of the weld joint. It may be caused by gravity or by the improper combination of heating rate and travel speed of the heat source.

Burn Through or Melt Through

Burn through or melt through is a convex or concave irregularity on the root surface or adjacent base metal. The irregularities may be voids caused by the falling away of weld metal or may be attached, solidified droplets. Excessive heating rate or insufficient travel speed of the heat source causes burn through. Also inadequate backing may permit burn through.

Underbead Cracking

Underbead cracking is a cracking in the heat affected zone. Such cracks may or may not extend to the surface of the weld joint. Underbead cracking is caused by hydrogen and excessive heating and cooling rates of the heat affected zone.

Location of Defects

Figure 28-1-9 shows the location in the weld of common weld defects.

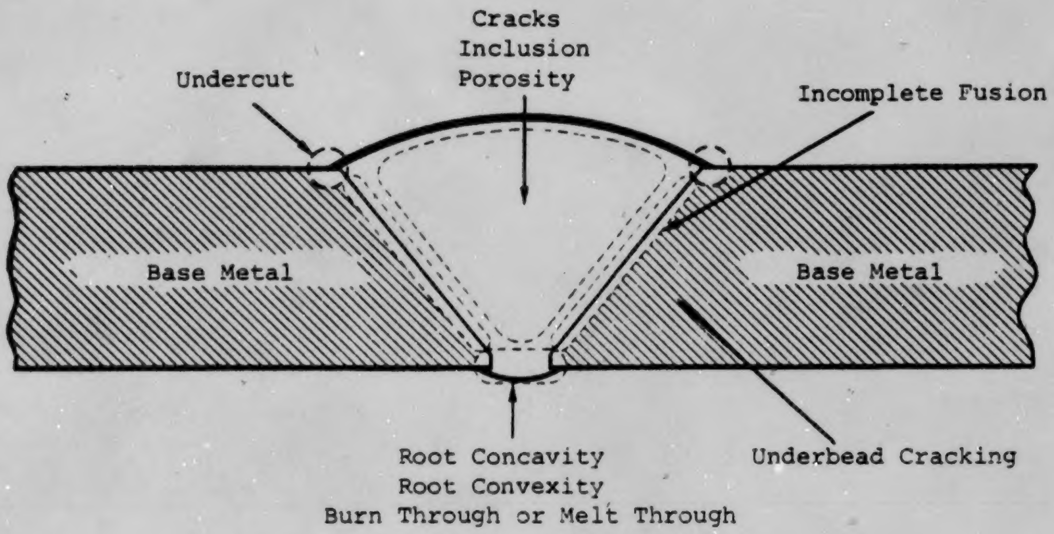

Cracks
Inclusion
Porosity
Undercut
Incomplete Fusion
Base Metal
Base Metal
Root Concavity
Root Convexity
Burn Through or Melt Through
Underbead Cracking

Figure 28-1-9 Location of Welding Defects

HEAT TREATMENT

Purpose

Carbon and low alloy steels have a tendency to crack when cooling rates are high. Other alloy steels, such as austenitic stainless steel, can have undesirable carbon migrations toward grain boundaries when they are welded. Further, hardenable alloys are hardened only in localized spots when welded. For these reasons, as well as other reasons, the welding engineer has to determine for each alloy that is to be welded, the effect that welding will have on the mechanical properties of the weldment. Whenever the welding engineer determines that some adverse effect due to welding is likely, he or she specifies a heat treatment countermeasure in the welding procedures. The QA/QC technician monitors the heat treatment to be sure that the specified counter measure is applied. The QA/QC technician also inspects the weldment after the heat treatment has been applied.

Heat treatment countermeasures commonly specified in the welding procedure include: preheating base metals prior to welding; controlling interpass temperature; and conducting past weld heat treatment.

Preheating

Preheating is the application of heat to the base metal prior to welding to bring the temperature of the base metal to the specified preheat temperature. Natural gas torches and electric induction heaters are two common heat sources for preheating.

Preheating retards the cooling rate in the weld metal and heat affected zone. It also lowers the magnitude of thermal stresses by reducing the temperature gradient from the weld metal to the surrounding base metal. The lower cooling rate permits recrystallization of weld metal with the desirable grain structure which does not have the tendency to crack. Hence, weld metal cracks and underbead cracks are avoided.

Interpass Temperature

Interpass temperature is the temperature of the weld metal before the next welding pass is started. It is measured immediately prior to starting the next pass. Interpass temperature is governed by the time interval between passes, i.e., how much cooling occurs prior to welding heat being reapplied.

Some steel alloys will form low strength crystals when cooling is particularly slow. In such cases, a maximum interpass temperature is specified and the welder must wait a sufficient time before welding the next pass to permit the interpass temperature to cool below the maximum.

Post Weld Heat Treatment

Post weld heat treatment is the application of heat to a weldment after welding is completed. If the weldment is portable, post weld heat treatment is normally accomplished in a furnace or oven. If the weldment is not portable, gas torches or electric induction heaters are used.

The nature of the post weld heat treatment is dependent on the properties of the particular alloy that has been welded. Some alloys do not require post weld heat treatment. In general, alloys that require preheating also require post weld heat treatment.

Stress relieving post weld heat treatment as the name implies, reduces the residual stresses from welding. In general, stress relieving is accomplished by heating the weldment to 1100 to 1200^{o}F, holding this temperature for one hour per inch of weld joint thickness, and slowly cooling from this temperature. The necessity for stress relieving increases with higher carbon content, increased alloy content, and larger cross-sectional areas of weldments. It is noted that mechanical stress relief by vibration is also finding increasingly wider use.

Stabilization heat treatment and solution anneal heat treatments are means of redissolving carbon into grain crystals. Such heat treatments are made necessary for alloys where welding drives carbon from solution into grain boundaries thereby weakening the corrosion resistance of the alloy and affecting its ductility.

WELDING PROCESSES

Five Types

Five welding processes are frequently used in nuclear power plant welding. They are: oxyacetylene welding, tungsten inert gas welding, shielded metal arc welding, metal inert gas welding, and submerged arc welding. This module briefly discusses the qualification of welding processes and the QA/QC technicians responsibilities during welding processes. It then describes each welding process and its uses. Later modules of this course present more detailed information on each welding process.

Qualification of Welding Processes

Each welding process affects the chemical and mechanical properties of the weld. Before any welding process can be used, its effects must be identified, examined and found acceptable through rigorous testing. The chemical and mechanical properties that result from a given welding process cannot be studied by nondestructive examinations of a weld. Rather these properties are studied by conducting various destructive tests on a test piece or test specimen of welded metal. The study of the weld's properties is often called "qualifying" the welding process. A welding process is said to be "qualified" if destructive and nondestructive testing of a test specimen reveal that the mechanical and chemical properties of the test specimen meet requirements set by the governing welding code or standard. For example, ASME Boiler and Pressure Vessel Code gives welding procedure qualification requirements in Section IX of the code.

A welding process is not requalified every time that it is used. It is known that, if a qualified welding process is applied without substantial change, the chemical and mechanical properties of the weld are essentially the same as the properties of the test piece.

The welding procedure specifies the welding process or processes that can be used for a given welding operation. The QA/QC technician monitors the welding process to assure that it complies with the specific welding procedure and that it is carried out within the limits of the qualification granted to the procedure. In order to perform this monitoring responsibility, the QA/QC technician needs to understand various welding processes and their accepted uses.

Oxyacetylene Welding

The oxyacetylene welding process is a fuel flame welding process that employs portable equipment that does not require external power sources. Oxygen and acetylene are fed from pressurized bottles to a mixing torch where the gases are mixed and ignited at the torch tip. The inner core of the flame (See Figure 28-1-3) is manipulated by the welder to control molten weld puddle size and flow. Shielding is provided by the outer envelope of the flame. Straight length bare rod (See Figure 28-1-5) is fed into the intersection of the core and the work piece where it melts and coalesces with the base metal molten puddle. Heating rate is dependent on size of torch and amount of time the flame is held in one location. The size of the molten weld puddle depends on the heating rate and the rate of adding filler material. This welding process is schematically represented in Figure 28-1-10.

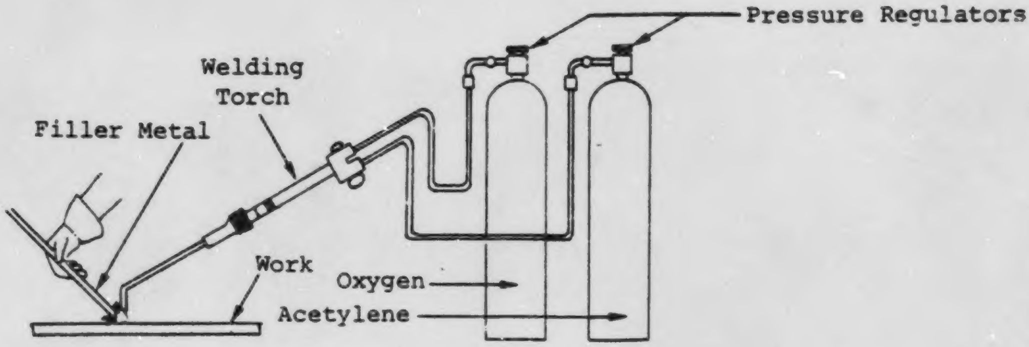


Figure 28-1-10 Schematic Diagram of the Oxyacetylene Welding Process

Uses of the Oxyacetylene Welding Process

Oxyacetylene welding is suitable for all types of base metals and joint designs, however, it is not frequently used for joint welding of steel because it is a relatively slow welding process and is not easily automated. It is used for joint welding of copper and aluminum base alloys, for hardsurfacing parts and occasionally for repair welding of small areas in any type of base metal. Hardsurfacing involves the use of a straight length bare rod that has high hardness, such as chrome, nickel-chrome, or cobalt-chrome. The surface of the deposited weld metal is comprised mostly of the filler material and therefore retains a very high hardness. The resulting surface gives good wear properties and is frequently used for surfaces which rub other surfaces in service (valve seating surfaces, for example).

Tungsten Inert Gas Welding

In this electric arc welding process, both electrical power and a shielding gas are fed through an electrode holder to the work piece. The arc is maintained between a tungsten electrode, which does not melt, and the work piece. Shielding gas (e.g., argon, helium) from a pressurized bottle flows around the electrode and the arc. Filler material must be supplied separately by feeding into the arc either straight length or spooled bare wire (See Figure 28-1-5). Equipment for the tungsten inert gas welding process is schematically represented in Figure 28-1-11.

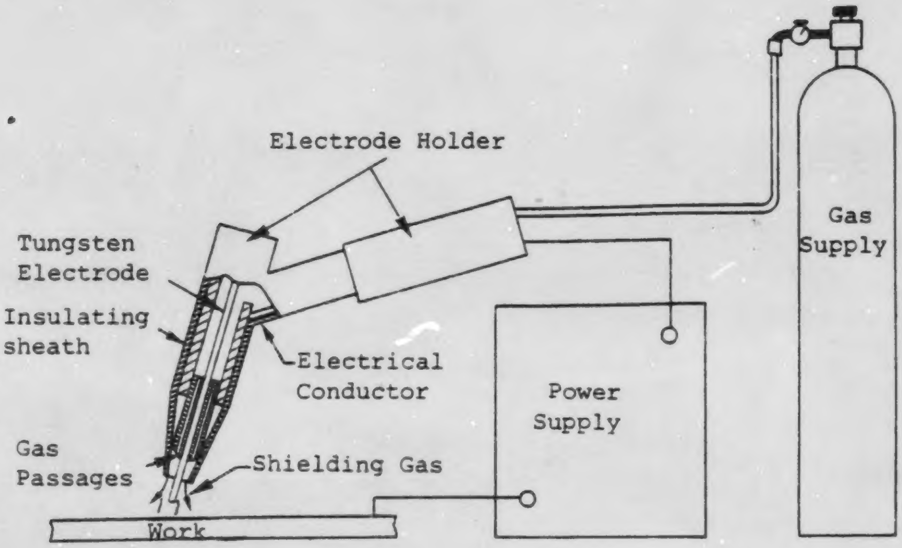

Electrode Holder
Gas Supply
Tungsten Electrode
Insulating sheath
Electrical Conductor
Power Supply
Gas Passages
Shielding Gas
Work

Figure 28-1-11 Schematic Diagram of the Tungsten Inert Gas Welding Process

Use of Tungsten Inert Gas Welding Process

Tungsten inert gas welding can be employed for all types of base metals and it is readily automated. Since no slag is present and precise heating rates are obtainable, it is often used for root pass welding. Its precise heating rates make it suitable for welding very thin parts and for welding in any position. The disadvantages of tungsten inert gas welding are: (1) It requires low to moderate welding speeds and (2) Any opening with a smaller diameter than the gas cup surrounding the tungsten electrode is inaccessible.

Shielded Metal Arc Welding

In shielded metal arc welding as in all electric arc welding, an external power source is needed. An electrical power supply provides voltage and current through electrical cables to an electrode holder and the work piece. The coated electrode (See Figure 28-1-5) completes the electrical circuit when it is struck against the work piece. The electrode's coating and core wire melt in the arc to provide shielding and filler material respectively. Heating rate is dependent on the voltage and current settings of the power supply. Arc length is manually controlled by the welder. Figure 28-1-12 depicts the shielded metal arc welding process.

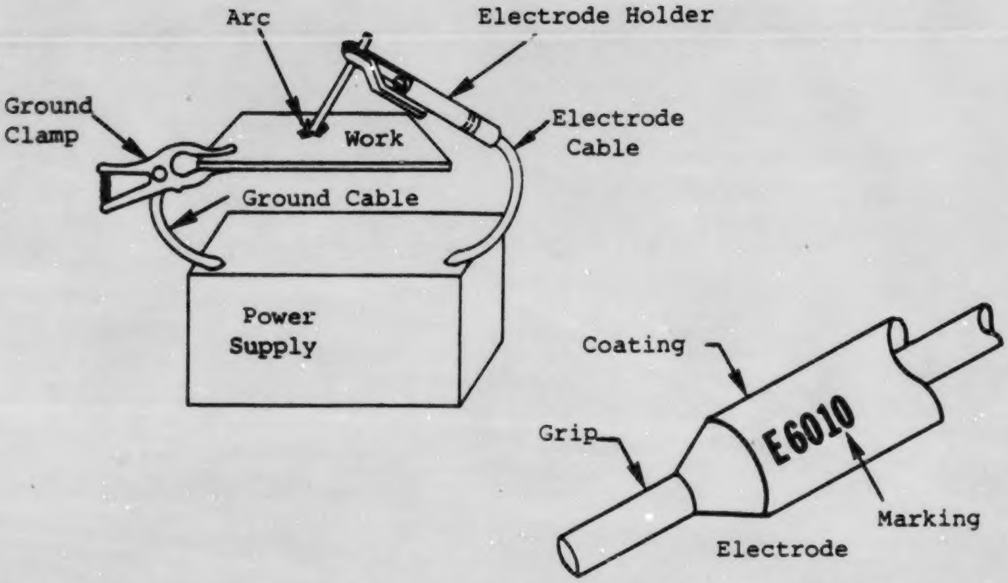

Arc
Electrode Holder
Ground Clamp
Work
Electrode Cable
Ground Cable
Power Supply
Coating
Grip
E6010
Marking
Electrode

Figure 28-1-12 Schematic Diagram of the Shielded Metal Arc Welding Process

Uses of Shielded Metal Arc Welding Process

Shielded metal arc welding is widely used for welding of ferrous and nickel alloys. It offers good control of size and flow of the molten weld puddle and it can be used in any position. However, it cannot be easily automated and it is a poor choice for root passes due to the risk of burn through and slag inclusions. Further, it is not readily adaptable to copper and aluminum base alloys.

Metal Inert Gas Welding

Complex equipment is needed for the metal inert gas welding process. In addition to an electrical power supply and pressurized shielding gas, controls are needed to feed bare wire into the arc at a sufficient rate. Since the arc is maintained between the bare wire and the work piece and the bare wire is constantly melting, wire feed rate must be set to maintain proper arc length with a given combination of electrical power and travel speed. Argon, helium or carbon dioxide may be used for shielding. Straight length of spooled bare wire may be used for filler material but spooled bare wire is mostly used to take advantage of the speed of this process. Heating rate is set by the power supply voltage and current and travel speed along the weld joint. Figure 28-1-13 shows the apparatus needed.

A long arc, called a "spray arc" is used for high heat and heavy material. The "short arc" is used for thinner work.

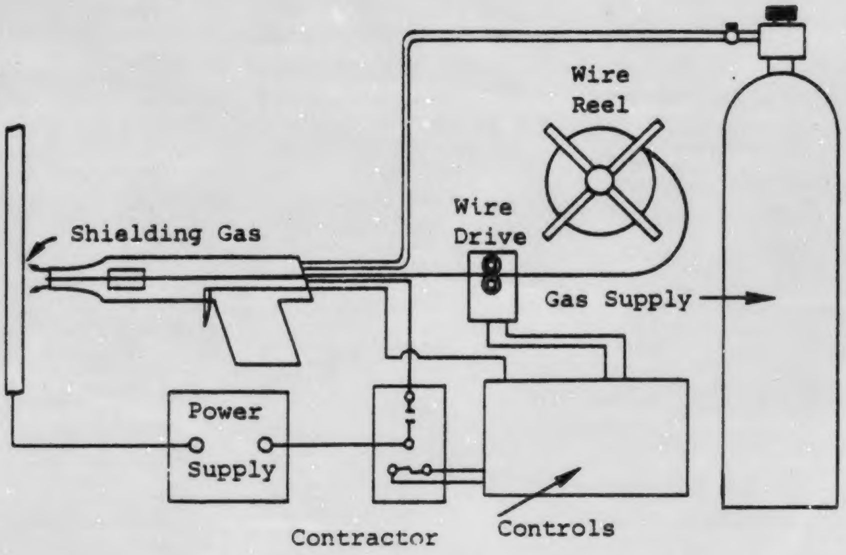


Figure 28-1-13 Schematic Diagram of Gas Metal Arc Welding Process

Uses of Metal Inert Gas Welding Process

The metal inert gas welding process can be used for all types of base metals. It is best suited for flat and horizontal welding positions and it is normally automated. Very high welding speeds are attainable. Disadvantages include accessibility requirements of the equipment, high installation costs, and likelihood of burn through with thin materials and fine porosity with any materials.

Submerged Arc Welding

Except for the absence of pressurized shielding gas, equipment for submerged arc welding is very similar to that used for metal inert gas welding. For example, spooled wire serves as both electrode and filler material and power supply and controls exist for synchronizing feed rate of the bare wire with the heating rate. The arc, however, is submerged in a granular flux that is preplaced on the work piece or fed through tubing surrounding the bare wire. The arc melts the base metal, bare wire and granular flux. The flux generates some shielding gases but provides a fairly thick, uniform molten slag that floats on the molten weld puddle and solidifies behind the travel of the arc. This slag protects the weld metal from adverse gases (oxygen, nitrogen). Figure 28-1-14 depicts the submerged arc welding apparatus.

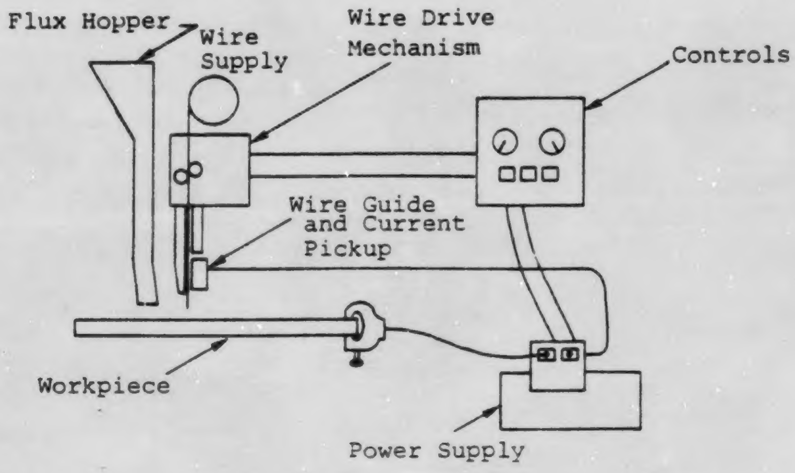

Flux Hopper
Wire Supply
Wire Drive Mechanism
Controls
Wire Guide and Current Pickup
Workpiece
Power Supply

Figure 28-1-14 Schematic Diagram of Submerged Arc Welding Process

Uses of Submerged Arc Welding Processes

Submerged arc welding is employed primarily for welding steel alloys. It is normally automated although it is adaptable to a hand held gun. The flat welding position is most favorable although coffer dams may be used for holding the granular flux for horizontal positions. As with metal inert gas welding, very high welding speeds are attainable but accessibility of equipment and inability to weld thin base metal thickness give limitations. The fine porosity from the metal inert gas welding process does not occur in submerged arc welding.

EXERCISES

The following exercises serve to reinforce the objectives presented in this module. Answer each question listed below. Refer back to the module only when necessary.

1. List the major duties of the QA/QC technician that are necessary during a welding inspection.
2. The configuration of the weld joint directly influences the strength of the joint, the ease of welding, and the probability of defect-free weldments. Identify the five basic types of joints used in welding.
3. List several considerations which must be made when choosing the type of welding joint.
4. The basic types of heat sources used in welding are fuel flame and electric arc. Briefly discuss the uses of each type.
5. The basic causes of distortion of the weld joint are the change in crystal size during welding and the temperature difference from the weld end faces to the

surrounding base material. Explain how distortion of the weld joint can be minimized.

6. Filler material is added to the joint to ensure that the weld is as thick as the base material. List the common types of filler rod.
7. What is the purpose of shielding during the welding process.
8. List the seven welding techniques that are common to all welding processes.
9. Each welding process has unique defects. However, there are nine defects that are common to practically all welding processes. List these nine types of defects.
10. Welding affects the mechanical properties of the weldment. Whenever there is an adverse effect on mechanical properties, heat treatment countermeasures are specified in the welding procedures. Briefly discuss the types of heat treatment countermeasures employed to minimize the effects on the mechanical properties of the weldment.
11. Perform the Procedures outlines in this module. These include:
    a. Gaining familiarity with welding reports
    b. Inspecting weld qualification test specimens
    c. Touring a welding shop and preparing a report.

MATERIALS

The following materials are required to support this module.

1. One or more issues of NUREG-0040, "Licensee, Contractor, and Vendor Inspection Status Report of Inspection and Inforcement (Optional; see Procedure #1).
2. Selected case studies of defective welds (optional; see Procedure #2).
3. Samples of welded joints, with and without defects.

PROCEDURES

1. Read NRC report NUREG-0040 (Quarterly Publication) Licensee Contractor and Vendor Inspection Status Report of Inspection and Enforcement on defective welds and prepare a brief written or oral summary of the report.
2. Read case studies of the consequences of defective welds. Prepare a brief written or oral report of one or more case studies.
3. Inspect weld qualification test specimens. Given the appearance of the specimen(s), identify the welding technique(s) used. Conduct a visual examination to locate defects.
4. Go on a guided tour of a welding shop. As you go through the welding shop, observe as many of the following items as possible. Answer the questions or fill in the information that is requested. Discuss the information in class.
    a. What type of welding process(es) is used? ____
    ____
    ____

    b. What apparatus is used? ____________________
    ____
    ____

    c. What heat source is used? ______________
    ____

    d. Describe the method of shielding. __________
    ____
    ____

    e. Describe the filler material. ____________
    ____
    ____

    f. Describe the welding technique. __________
    ____

g. What, if any, visible defects are present in the finished weld? ______________________________

____

____

DATA TABLE

None.

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Sections III and IX, 1979, The American Society of Mechanical Engineers

AWS, Structural Welding Code, AWS D1.1 and Reinforcing Steel Welding Code, D12.1, American Welding Society

ARCOS, Arcos Pamphlet GC47620, Welding Products, Arcos Corporation, 1500 South 50th. Street, Philadelphia, Pennsylvania.

TEST

MATCHING: Match each term given in the left-hand column with the correct definition given in the right-hand column. Place the letters of the definitions next to the terms they match.

1. ____ heat affected zone
2. ____ weld metal
3. ____ fusion zone
4. ____ toe
5. ____ reinforcement
6. ____ included angle
7. ____ weld end face
8. ____ root gap

a. The base metal whose chemistry and physical properties are unaffected by the welding process.

b. The distance between the surfaces to be welded as measured at the bottom of the weld joint.

c. The volume of base metal and filler material in the vicinity of the weld end faces which melts and resolidifies during the welding process.

d. The interface of either side of the weld metal with the base metal along the logitudinal surfaces of the weld joint.

e. Volume of base metal that does not melt but whose physical properties are altered by welding heat.

f. Surface area of the surfaces to be welded.
g. Controlled movement of the flame along the weld joint to permit melting of new areas.
h. Angle formed by perpendicular centerline of the weld joint and weld end face.
i. Volume of metal whose chemistry and physical properties are the same as the mixture of added filler and base metal.
j. Weld metal thickness in excess of nominal base material thickness specified for the weld joint.

Multiple Choice: Circle the letter of the response that best completes statements 9 through 16.

9. The lap joint is used only in areas where:
   a. the highest stress will be applied
   b. the stresses throughout the joint can be equalized
   c. there is low stress or moderate stress in the direction parallel to the plate surfaces
   d. the weave bead technique can be used

10. The heat source used in welding must be able to:
    a. input heat rapidly in order to melt weld end faces only
    b. bring the metal mass to the melting point of the base metals
    c. melt weld end faces and base metals
    d. create new crystals that are different in size from the base metal crystals

11. When there is a large temperature difference (gradient) between the weld end faces and the surrounding base metal:
    a. complete fusion takes place easily
    b. there is no need to physically restrain the parts to be welded
    c. weld joint distortion is minimized because thermal stresses are reduced
    d. weld joint distortion due to internal stresses is likely to occur

12. When the weld metal is formed solely by melting the weld end faces:
    a. the weld is thinner than the base metal
    b. the weld and the base metal are of the same thickness
    c. the welded places are thicker than the base metal
    d. only a small amount of heat input is needed to make a successful weld

13. The purpose of shielding in welding is:
    a. to prevent the welder from being in direct contact with the heat source
    b. to encourage the formation of oxides and nitrides in the weld
    c. to displace hydrogen, nitrogen and oxygen from the vicinity of the weld joint with a substance not harmful to the weld
    d. to conduct oxygen to areas of the weld where it can have the most beneficial effect on the heat source

14. In the forehand and backhand welding technique it is possible to shape the molten weld puddle because:
    a. fewer passes of the heat source are used
    b. the flame or electric arc exerts a force which pushes the molten puddle in the direction of the force
    c. the fusion zone constantly changes from weld end face to weld bead
    d. very low heating rates can be used

15. There is a relatively high probability of incomplete fusion in the weave bead technique because:
    a. so few weld beads are used
    b. gravity attracts the molten weld puddle
    c. pure oxygen is likely to combine with nitrogen to form harmful nitride
    d. the weld puddle is pushed in several directions and the fusion zone alternates between weld end face and weld bead

16. The positional welding techniques that have the highest degree of difficulty for making a sound weld are:
    a. interpass cleaning technique and vertical progression
    b. flat and vertical
    c. overhead and vertical
    d. reverse side and vertical progression

Completion:

Fill in the name of the defect which is described by each phrase for questions 17 through 24.

17. A cracking in the heat affected zone caused by hydrogen and excessive heating and cooling rates. ____

18. Excessive reinforcement at the root of the weld. ____

19. Failure to melt together the filler metal and the base metal. ______________________________

20. An intermittent or continuous depression along the toe or root of the weld left unfilled by weld metal. ____

21. A convex or concave irregularity on the root surface or adjacent base metal caused by the falling away of weld metal. ______________________________

22. A depression in the root surface of the joint that can be caused by gravity. ____________________

23. Cavities in the weld metal caused by trapped gases.

____

24. Entrapped foreign material in the weld metal. ______

____

Fill In:

Fill in the name of the welding process that best meets the description given in questions 25 through 34.

25. In addition to an electrical power supply and pressurized shielding gas, this process requires controls to feed bare wire into the arc at a sufficient rate.

____

26. This process can be used in any position because it offers good control of size and flow of the molten weld puddle. ____________________

27. In this process, the arc is maintained between the bare wire and the work piece and the bare wire is constantly melting. ____________________

28. In this process, the arc is in a granular flux that is preplaced on the work piece or fed through tubing that surrounds the bare wire. ____________________

29. In this welding process, which does not use pressurized shielding gas, spooled wire serves as both the electrode and the filler material and the power supply and control synchronize the feed rate of the bare wire and the heat rate. ____________________

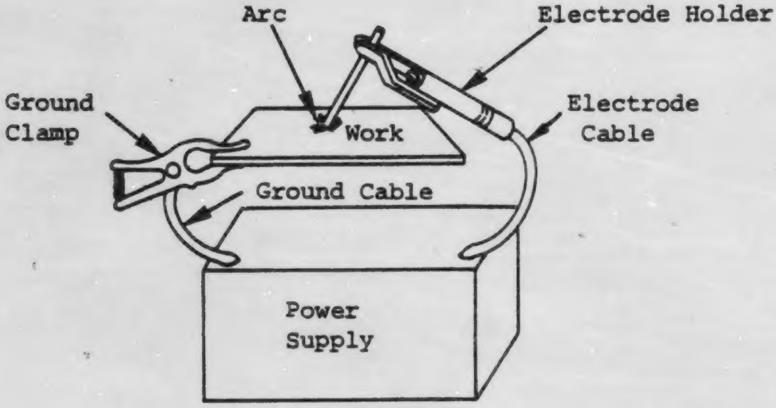
30. In this welding process, the electrode's coating melts to provide the shielding and the core wire melts to provide filler material. ____________________

31. This process is often used for root pass welding because precise heating rates are obtainable and because no slag is present. ____________________

32. This process permits only a slow to moderate welding speed and cannot be used to weld diameters smaller than the cup surrounding the electrode. ____________________

33. This is a fuel flame welding process in which the welder manipulates the inner core of the flame to control weld puddle size and flow and in which the outer envelope of the flame provides shielding. ____________________

34. This process uses the apparatus shown on next page.
____


Arc
Electrode Holder
Ground Clamp
Work
Electrode Cable
Ground Cable
Power Supply

NUCLEAR TECHNOLOGY

MODULE 28-2

SHIELDED METAL ARC AND OXYACETYLENE WELDING

COURSE 28 WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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INTRODUCTION

The Nuclear QA/QC technician frequently performs verification, monitoring, and inspection tasks related to oxyacetylene and shielded metal arc welding. Verifications include qualifications of procedures and welders and correctness of materials. Monitoring includes checks for compliance with welding procedures. Inspections include fit-up and final weld inspections.

The oxyacetylene and shielded metal arc welding processes are two widely employed methods of joining metallic parts. Their equipment is relatively inexpensive and transportable, thereby making these processes popular in welding shops and field welding applications. However, neither is well suited for automation and consequently, their welding speed is slow.

This module describes the key features of these two welding processes. The apparatus, process techniques, procedures, applications, associated defects and inspections are presented. The student/trainee should approach this module from the viewpoint of how each welding process makes (or fails to make) a sound weld. It will become evident that each process contains key features which if employed properly, can produce high quality weldments.

Knowledge of these welding processes should equip the student/trainee to understand the basis for the qualifications, process controls and inspection requirements presented in later modules of this course.

MODULE PREREQUISITES

The student/trainee should have prior training or experience on welding fundamentals. Completion of Module 28-1 of Nuclear Technology satisfies this prerequisite.

OBJECTIVES

Upon completion of this module the student/trainee can:

1. State the function of major equipment components of the oxyacetylene and shielded metal arc welding processes.
2. List the techniques employed by the welder and state their effects on the quality of the weld for each of the two welding processes.
3. Arrange given steps of an oxyacetylene or shielded metal arc welding procedure in correct sequence.
4. Describe effects of given essential variables of the two welding processes on weld quality.
5. Identify potential sources of given defects and state how these sources can cause the defect.
6. List the types of defects that can be detected with a given type of inspection and briefly describe the method of detection.

OXYACETYLENE WELDING

Equipment

Heat from oxygen-fuel gas combustion offers a convenient means of welding. The necessary equipment is portable and requires no external power source, such as electricity. Hydrogen, natural gas, propane and other fuel gases may be used as the fuel gas, but acetylene is most commonly used, due to its high heating capacity. The oxyacetylene flame provides for fusion and shielding simultaneously. Filler material is fed separately into the flame.

Basic equipment needed for the oxyacetylene welding process is shown in Figure 28-2-1.

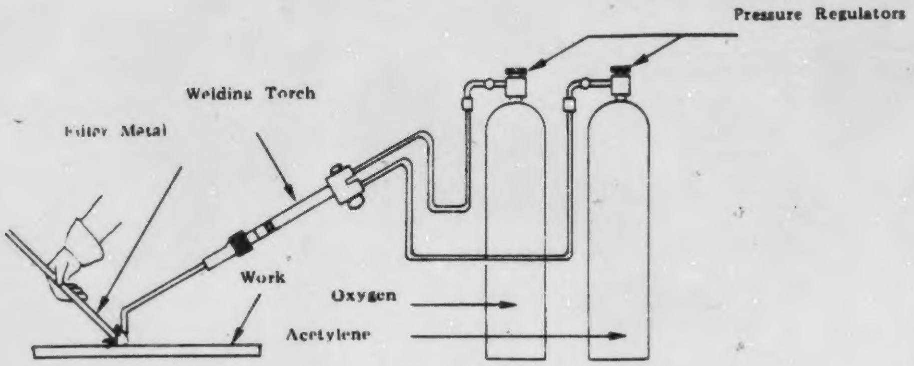


Figure 28-2-1. Equipment for Oxyacetylene Welding

When using oxyacetylene welding equipment, one safety precaution should always be observed: THE GAS BOTTLES SHOULD ALWAYS BE CONSTRAINED BY CHAIN OR BELT STRAPPING TO PREVENT TIPPING THEM OVER. If the connections at the neck of the bottles are broken, the escaping pressurized gas makes the bottle become a projectile, capable of damaging equipment and injuring personnel.

Process Techniques

For oxyacetylene welding, oxygen and acetylene are fed, individually, through pressure regulating valves, through hoses and into the welding torch. As shown in Figure 28-2-2, the welding torch consists of a mixing section and a tip. While the primary adjustment for gas flow is made by setting the pressure regulating valves, the needle valves on the mixing section can "fine tune" the flame. Torch size determines heating capacity. Larger torch sizes permit greater volume of gas flow and, consequently, larger heating capacity.

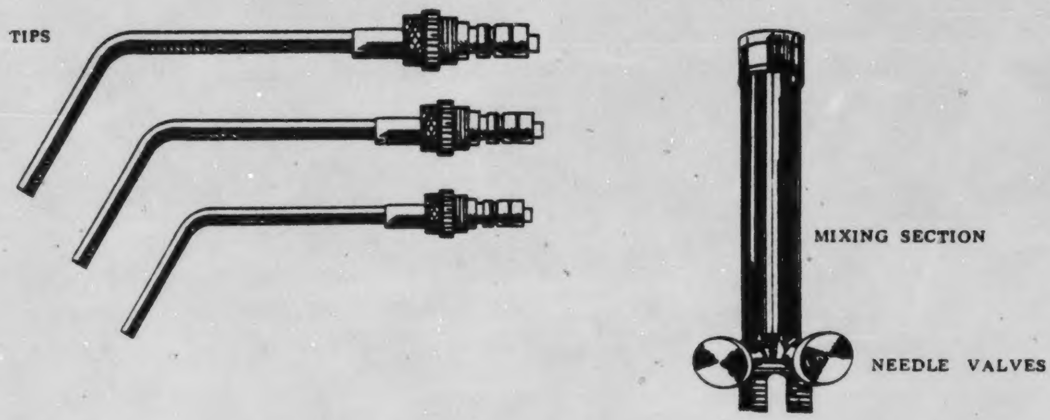
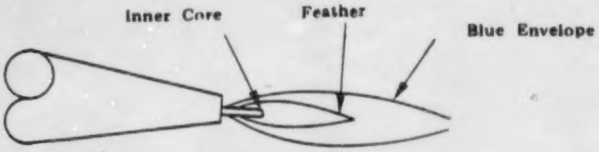
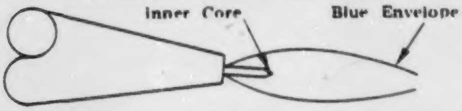


Figure 28-2-2
Oxyacetylene Welding Torch

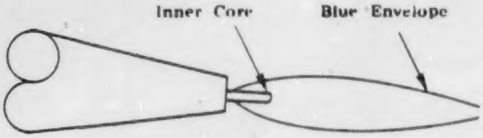
Varying the amount of oxygen and fuel gas in the gas flowing to the tip of the torch produces different welding atmospheres and different flame temperatures. The type of flame selected must be compatible with the base material to prevent the base metal from being adversely affected by the flame. Generally, the welder makes adjustments to the gas flow, based on the appearance of the flame. The welder is able to make these adjustments because, as the acetylene-oxygen mixture burns from the tip of the welding torch, several clearly recognizable zones of combustion appear. Figure 28-2-3 shows the conditions visible during adjustment of the oxyacetylene flame and identifies that three types of flames are possible. These are neutral, carburizing and oxidizing flames.



Oxyacetylene Flame - Carburizing



Oxyacetylene Flame - Oxidizing



Oxyacetylene Flame - Neutral

Figure 28-2-3
Conditions of Oxyacetylene Flames

Neutral Flame

The neutral flame appears when equal amounts of oxygen and acetylene are burning. A neutral flame does not react with the metal. When the flame is neutral, neither excess acetylene nor excess oxygen are present at the tip of the inner cone. A neutral flame can be obtained by careful observation of the size and color of the combustion zones in the flames, while adjusting the torch inlet valves. In a neutral flame, the pale blue inner cone is from 1/16 to 1 inch long, depending on the size of the torch; and it is sharply defined. The bluish outer envelope serves as shielding during welding.

Carburizing Flame

By increasing acetylene flow in excess of oxygen flow, a third zone appears which is termed "feather" or "acetylene feather". The inner cone remains sharply defined and the bluish outer envelope exists. The length of the whitish feather is proportional to the amount of excessive acetylene flow and is measured in terms of the inner cone. If x equals the length of the inner cone and the feather is twice as long, a 2x feather exists. A 3x feather is three times as long as the inner cone and so on. Because the feather contains white hot carbon particles, this flame is called "carburizing". The carburizing flame scavenges oxygen, which could otherwise cause oxides and is typically employed in welding aluminum and steel and for hard-surfacing with nickel, chrome or cobalt alloys.

Oxidizing Flame

If oxygen flow is increased in excess of acetylene flow, an oxidizing flame results. The oxidizing flame has only two zones but, unlike the neutral flame the inner cone is shorter, necked on its sides, and becomes darker blue or purplish. The outer envelope is more turbulent. The oxidizing flame is used for welding various grades of brass and bronze.

To begin oxyacetylene welding, the flame is applied to the base metal until melting occurs. Then, bare filler rod is fed into the flame where it melts and flows into the molten base metal. The angle of the torch is manipulated to control puddle flow. Both distance from the work piece and movement of the torch control heating rate, (given a fixed torch size). Movement of the torch is in small increments to permit the flame envelope to shield the molten puddle until resolidification occurs.

Welding Procedures

Written welding procedures prescribe the specific materials, equipment, and techniques that the welder must use. The welding procedure is based on previous successful use in production welding or in welding qualification test pieces. It provides a technically acceptable method of standardizing welds that are produced, controls the quality of the weld, and helps to ensure defect-free welds.

There is a separate welding procedure for each group of similar joints. The welding procedure lists variables that provide instructions to the welder. These variables are sub-divided into two categories: essential and non-essential. Those that establish the limit of qualification of the procedure are called essential variables. The remaining variables are called non-essential. Both types are necessary for a quality weld. Welding codes establish the essential and non-essential variables for each welding process. Table 28-2-1 lists typical essential and non-essential variables for the oxyacetylene welding process. (If Table 28-2-1 were an actual welding procedure, specific values or types of gas or materials would be inserted.)

TABLE 28-2-1, PROCEDURE VARIABLES FOR OXYACETYLENE WELDING

Fundamental Variables	Essential Variables	Nonessential Variables
1. Joint Design	(none)	(a) groove type & design (b) use of backing (c) material type of backing
2. Base Metal	(a) material type (b) joint thickness	None
3. Filler Material	(a) material type (b) deposited weld metal chemical composition	(a) size of bare rod
4. Position	(none)	(a) the welding position to be used
5. Preheat	(none)	(a) the minimum preheat temperature to be maintained
6. Postweld heat Treatment	(a) heat treatment temperature	(none)
7. Gas	(a) type of fuel gas	(none
8. Technique	(a) for hard surfacing only, oxygen and acetylene pressures and torch size.	(a) stringer or weave bead (b) nature of flame (neutral, carburizing, or oxidizing) (c) forehand or backhand (d) method of initial and interpass cleaning

Essential and Non Essential Variables

The decision to classify a variable as essential or nonessential depends primarily on the effect the variable would have on the physical strength of the weld joint. This decision is also based on the advantages and disadvantages of the welding process. It assumes that the welder is doing to follow the given welding procedure and assumes that the welding engineer specifies welding processes and joint designs that are compatible.

Notice in Table 28-2-1 that joint design and position are considered nonessential variables in oxyacetylene welding; this is because oxyacetylene welding is adaptable to all joints in all positions. On the other hand, material type and thickness, deposited weld metal chemical composition, heat treatment temperature, and type of fuel gas are essential variables. These variables affect such things as weldability, heating rate, and weld strength.

Once a welding procedure is qualified, it may be used in any application where essential variables remain the same. However, if one or more essential variables must be changed in order to adapt the welding procedure to a specific joint, the revised procedure must be requalified by welding and testing a special qualification test piece.

Oxyacetylene Procedure

The oxyacetylene welding procedure covers the essential and non-essential variables listed in Table 28-2-1. The procedure establishes joint fit-up requirements and the welding techniques to be employed.

As with all welding processes, the weld joint needs to be clean. Foreign materials (such as oil, dirt, chips, scale) will typically vaporize or melt in the weld puddle, thereby increasing risk of porosity and inclusions.

Welding procedures typically specify the method of cleaning and the cleanliness acceptance criteria to be applied immediately prior to commencement of welding. The procedure will also specify interpass cleaning method to assure clean surfaces between passes. The oxyacetylene welding process produces a relatively clean weld bead and requires little interpass cleaning.

Penetration (depth of melting of base metal) is governed by torch size and welder's techniques since the combination of these two variables establishes the heating rate. Joint welding by oxyacetylene requires relatively deep penetration which is obtained by the welder's techniques. Hard surfacing by oxyacetylene requires relatively shallow penetration to give a resultant weld bead whose surface is essentially comprised of the hard filler material. Therefore, for hard surfacing, the torch size and associated gas pressures become essential variables.

Application

Oxyacetylene welding can be universally applied. However, because its weld metal deposition rate is low, compared to other welding processes, it is mostly used where other welding processes have serious disadvantages. For example, welding of copper and aluminum base alloys is easier with oxyacetylene welding than with most of the electric arc processes. Oxyacetylene gives the high heating rate and precise control of the heating rate needed for these alloys. Also, depth of penetration is easily controlled by the oxyacetylene welding process which makes it especially suitable for small parts in the overhead and vertical position.

Characteristic Defects; Their Causes and Detection

Defects most likely to occur with the oxyacetylene welding process are listed in Table 28-2-2 along with their causes and means of detection.

Table 28-2-2

Characteristic Defects For Oxyacetylene Welding

DEFECT	PROBABLE CAUSE	DETECTABLE BY
Undercut	Insufficient addition of filler material; insufficient number of passes.	Visual inspection; radiography.
Burn Through	Torch too large; holding flame in one area too long.	Visual inspection; radiography.
Porosity	Oxidizing flame; too sudden removal of flame envelope.	Liquid penetrant or magnetic particle for surface; radiography for subsurface.
Crack in the weld metal	Torch too large; incorrect filler material; incorrect base metal.	Liquid penetrant or magnetic particle for surface; radiography or ultrasonic for subsurface.
Underbead Crack	Torch too large; Insufficient preheat.	Radiography or ultrasonic.
Incomplete Fusion	Joint inaccessability; improper control of torch angle.	Radiography or ultrasonic.

Undercut and burnthrough are visually discernable; therefore, visual inspection of the completed weld suffices for detection of undercut and burnthrough if both sides of the weldment are visible. If the inside is not accessible for visual inspection, radiography can be used.

Porosity and cracks may be open to the surface or completely sub-surface. Either liquid penetrant or magnetic particle testing has the capability to detect porosity and cracks that are open to the surface. Liquid penetrant tests employ a colored or flourescent fluid, that penetrates openings to the surface and a subsequent developing technique that attracts the penetrant from the openings. For any areas in which the developer pulls penetrant from openings, a color contrast is visible, which indicates the defect. For example, red penetrant attracted by white developer would show red rounded indications if porosity were present and red linear indications if cracks were present. To detect defects, magnetic particle testing induces a magnetic field into the weldment. Porosity and cracks disrupt the magnetic field. When magnetic particles are sprinkled onto the weldment, the magnetic particles concentrate at the points of disruption of the magnetic field and thereby show the defect. Radiography detects subsurface porosity and cracks. X-ray, or gamma rays, are directed at the weldment, toward film preplaced on the opposite side of the weldment. A percentage of the x or gamma rays pass completely through the weldment and darken the film. In areas where porosity or cracks are present, more rays pass through the weldment because there is less weld metal to absorb the rays. In these areas, greater darkening of the film will occur. When the film is developed, porosity shows up as a rounded dark area; cracks show up as linear dark areas. Ultrasonic testing can also be used to detect cracks. In this test method, ultrasonic sound waves are directed through the weldment. If cracks are present, the sound waves reflect back from the crack to a sensor where the reflected signal is amplified and displayed on an oscilliscope or recorder. Ultrasonic testing also detects gross porosity in the same manner but is not sufficiently sensitive to detect fine porosity.

Underbead cracks and incomplete fusion can be detected by either radiography or ultrasonic testing. Techniques are the same as those used for detecting cracks in the weld metal.

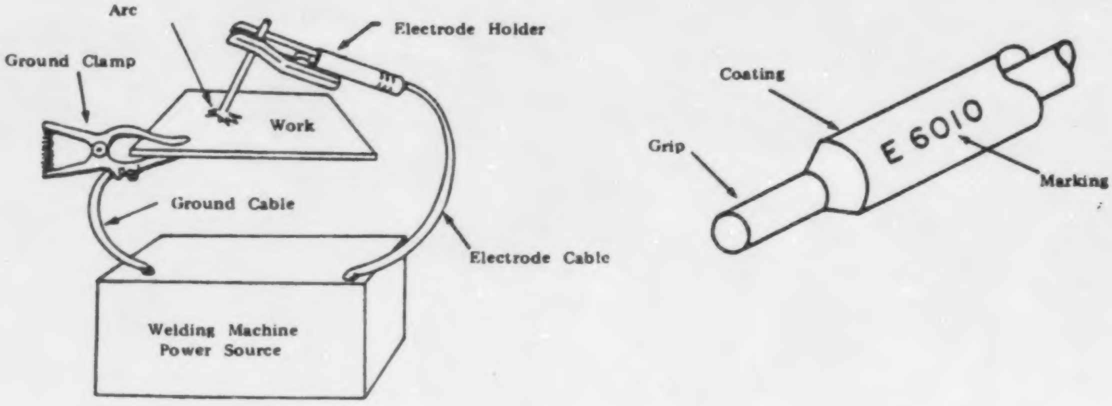
The specific inspections for welds made by oxyacetylene welding depend on the acceptance criteria specified for the weldment. Considering such factors as strength requirements and stress the weldment will see in service, the design engineer determines the types and sizes of defects which do not permit satisfactory service by the weldment. For example, if only cracks, undercut and burn through are of concern, adequate inspection can consist of visual inspection and radiography or if the backside of the weld is accessible, visual inspection and ultrasonic testing are adequate.

SHIELDED METAL ARC WELDING

Equipment

The shielded metal arc welding process (SMA) produces heat for fusion by an electric arc between a coated electrode and the work. The coated electrode provides filler material and shielding. An electrical power supply provides current and voltage for maintaining the arc.

Basic equipment needed for shielded metal arc welding are shown in Figure 28-2-4


Arc
Electrode Holder
Ground Clamp
Work
Ground Cable
Electrode Cable
Welding Machine Power Source
Coating
Grip
E 6010
Marking

(a) Apparatus (b) Electrode

Figure 28-2-4
Apparatus for SMA

The power supply provides voltage and current in one of several modes. Direct current, i.e., current flow in only one direction, is typically used, although alternating current, i.e., current that alternately changes direction of flow, can be employed for certain electrodes. The holder consists of an electrically insulated handle and vice type jaws for clamping the grip section of the electrode. Current flow path is completed by connecting the ground cable from the power supply to the weld joint to be welded. The coated electrode has the triple duty of providing arc, shielding and filler material.

Process Techniques

The events in and around the SMA arc are pictured in Figure 28-2-5.

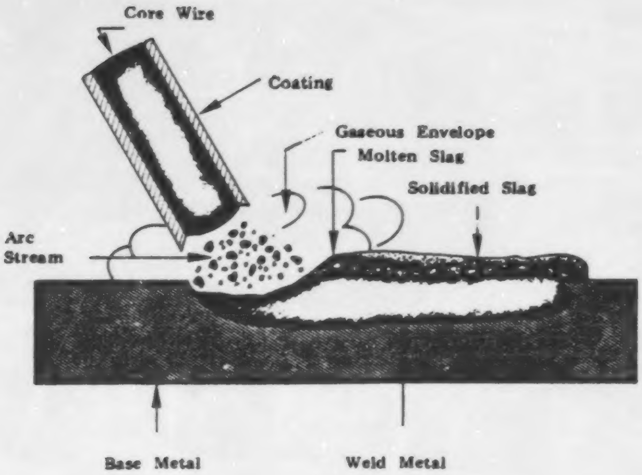
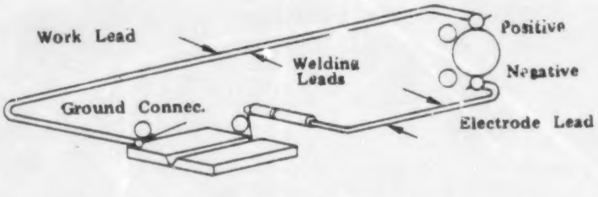

Core Wire
Coating
Gaseous Envelope
Molten Slag
Solidified Slag
Arc Stream
Base Metal
Weld Metal

Figure 28-2-5
SMA Process

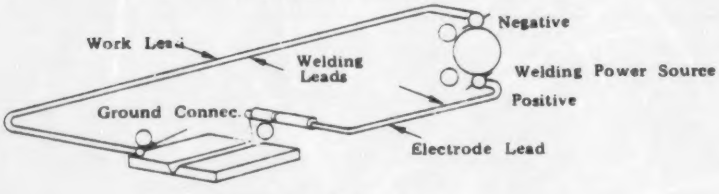
Heat from the arc simultaneously melts the inner core wire, the electrode coating and some depth of base metal. Melting of the coating generates gases which displace air to provide shielding. Other portions of the coating form slag which floats on the weld puddle and whose trailing edge solidifies as the electrode moves along the weld joint. This slag shields the hot weld metal from oxidation. Also, most coatings contain metallic ingredients which melt and coalesce with the weld puddle. Such ingredients help achieve the desired chemistry of the weld metal. However, almost all of the filler metal comes from the core wire. Tiny droplets of metal stream from the core wire and coalesce with the molten base metal.

Pentration (depth of base metal that is melted) is dependent on a number of factors. The primary factor is the current density in the arc which is a function of current and diameter of the coated electrode. Penetration increases as current is increased given a constant diameter electrode. Likewise, penetration increases as electrode diameter is decreased given a constant current value.

Penetration is also affected by the polarity of direct current. Either straight polarity or reversed polarity may be used as shown in Figure 28-2-6.


Work Lead
Welding Leads
Positive
Negative
Ground Connec.
Electrode Lead

A Straight Polarity


Work Lead
Welding Leads
Negative
Welding Power Source
Positive
Ground Connec.
Electrode Lead

B Reversed Polarity

Figure 28-2-6
SMA Direct Current Polarity

The gases generated by melting of the electrode coating ionize in the arc. These gas ions aid current flow through the arc and tend to stabilize the arc, i.e., reduce whipping or turbulance in the arc. Since the positive gas ions cause more effect than negative ions due to their larger size, the direction of flow of the positive ions is important. With straight polarity as shown in Figure 28-26a, positive gas ions flow against the stream of core wire droplets toward the negatively charged electrode. This flow causes some flare in the arc and imparts energy against the flow of core wire droplets. Consequently, less penetration occurs with straight polarity for a given combination of current and electrode diameter. The opposite occurs with reversed polarity. The flow of positive ions toward the negatively charged work piece tends to keep a cylindrical arc and add energy to the stream of core wire droplets. Thus, more penetration occurs with reversed polarity for a given combination of current and electrode diameter.

Arc voltage primarily determines the stability of the arc. The voltage is set at the welding power supply to a value which gives a stable arc with a given combination of current and electrode diameter. Within this power supply setting, arc voltage will vary with the arc length maintained by the welder. As SMA welding progresses, the welder continuously feeds the electrode into the arc, moves the arc along the weld joint, and controls weld puddle shape and flow by the angle of the electrode. With these three motions, the welder attempts to maintain a constant arc length in order to maintain proper arc voltage.

The effects of arc length on arc stability are illustrated by Figure 28-2-7

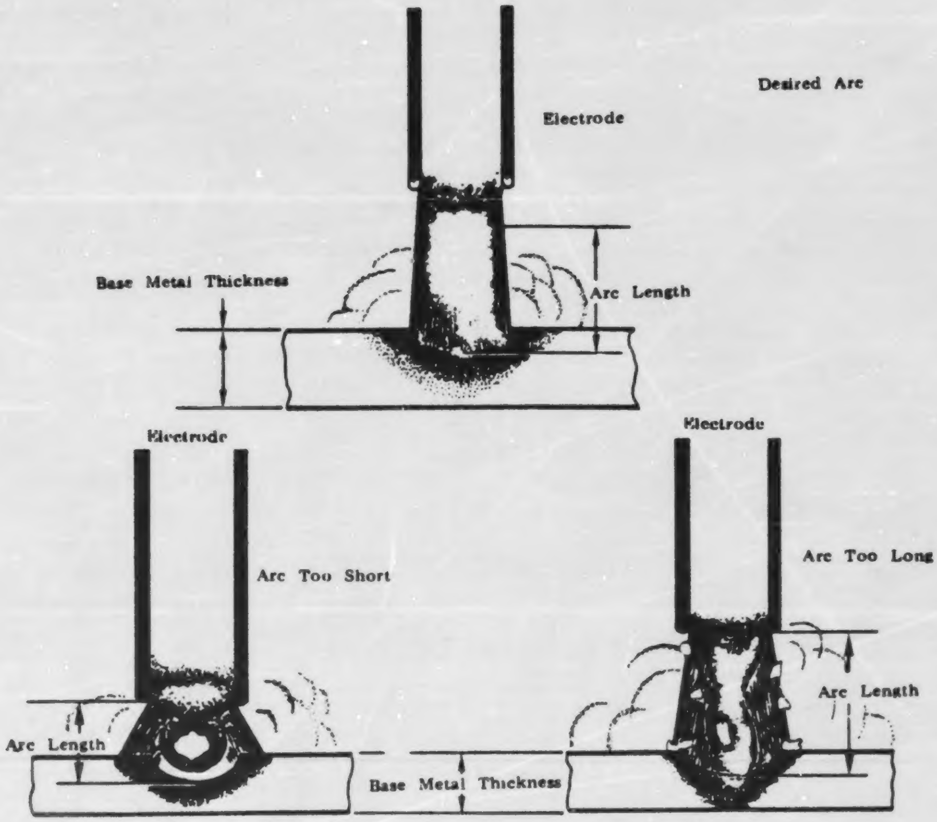

Desired Arc
Electrode
Base Metal Thickness
Arc Length
Electrode
Arc Too Short
Arc Length
Electrode
Arc Too Long
Arc Length
Base Metal Thickness

Figure 28-2-7
SMA Arc Length Variations

Arc length that is too short results in more pentration and a more narrow and raised weld bead. Arc length that is too long results in less penetration and a wider and flatter weld bead. In either case, the arc tends to become unstable. Arc turbulance can cause inadequate shielding resulting in porosity in the weld. Arc turbulance also increases weld spatter. Weld spatter always occurs to some extent with shielded metal arc welding.

It consists of droplets of molten metal sprayed from the arc to surrounding areas. Such spatter that attaches to the base metal causes localized hard spots which must be removed in many welding applications to prevent crack initiation from the hardened area.

SMA Procedure

Table 28-2-3 lists typical essential and nonessential variables for the shielded metal arc welding process. SMA welding procedures give specific values for each variable.

These variables for SMA welding are classified as essential or nonessential using the same rationale as that described for the oxyacetylene welding process.

Interpass cleaning becomes particularly important for shielded metal arc welding. Slag formed by melting the electrode coating adheres to the solidified weld bead and must be removed prior to welding the next pass. A chipping hammer will normally loosen the slag such that a wire brush will sweep it from the weld. Grinding may be required along the edges of the weld bead and at the stops.

Angle of electrode is not listed in Table 28-2-3 because the angle is most favorable to complete fusion and good bead contour. In multi-pass SMA welding, the welder controls bead contour to avoid generating crevices where slag can be entrapped. If necessary, the welder will grind between passes to open crevices.

Maxium interpass temperature is an important variable when welding alloys susceptible to formation of undesirable grain structure when cooling is excessively slow. The SMA welding process has the capability of continually increasing base metal temperature when there are short time intervals between passes.

Table 28-2-3

Procedure Variables for Shielded Metal Arc Welding

FUNDAMENTAL VARIABLE	ESSENTIAL VARIABLES	NONESSENTIAL VARIABLES
1. Joint Design	(None)	(a) groove type and design (b) use of backing
2. Base Metal	(a) material type (b) joint thickness	(None)
3. Filler Material	(a) filler material type (b) deposited weld metal chemical composition	(a) diameter of electrode
4. Position	(a) where impact properties are tested, the welding position to be used	(a) for all other applications, the welding position to be used.
5. Preheat	(a) the minimum preheat temperature to be maintained (b) where impact properties are tested, the maximum interpass temperature permitted	(a) whether preheat is to be maintained after welding prior to post weld heat treatment (b) maximum interpass temperature
6. Post Weld Heat Treatment	(a) heat treatment temperature and time	
7. Electrical Characteristics	(a) where impact properties are tested, the current type (DC or AC), polarity (straight or reversed) and value (amperage) also, voltage	(a) for all other applications current type and polarity (b) current and voltage values
8. Technique	(a) where impact properties are tested and for vertical welds, the vertical progression (up or down)	(a) stringer or weave bead (b) method of initial and interpass cleaning (c) method of backgouging (d) use of nonmetallic retainers (e) vertical progression (f) whether manual or semiautomatic

Where the procedure specifies a maximum interpass temperature, the welder ensures sufficient cooling has occurred prior to welding the next pass.

Procedural Sequence

Procedural steps are arranged to give instruction on (1) requirements prior to welding (2) requirements during welding and (3) requirements after welding. Requirements prior to welding pertain to cleanliness and fitup of weld joint members. Requirements during welding are the specific welding parameters and techniques to be used by the welder. Requirements after welding are those pertaining to post weld heat treatment and acceptance inspection. A sample SMA welding procedure is given by Figure 28-2-8.2-8. It is noted that the backing ring in the sample procedure is of the same material as the base material. This means that good penetration and fusion of the backing ring will occur. This is typical of situations where backing rings are left in place. Where backing rings are removed after welding, they may be of an alloy which has a considerably higher melting point such that poor fusion of the backing ring occurs. This would make removal of the backing ring easier.

ABC Company

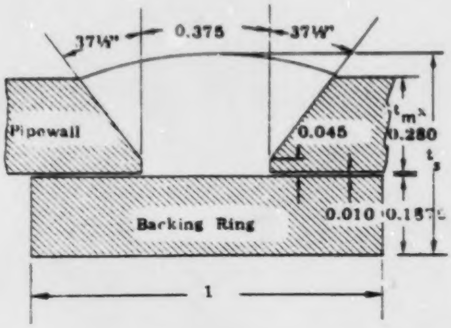
SMA Welding Procedure 101	Revision A	8/23/79

Joint Design and Fit-up

- joint design: double V butt with backing ring
- base material:
  - pipe: six inch schedule 80, alloy 715 copper - nickel per SB-466
  - backing ring; alloy 715, copper nickel per SB-171
- fit up dimension: per sketch #1

Welding Paramenters

- process manual sheilded metal arc
- filler metal: ECuN: coated electrodes per AWS A5.6
- welding current; direct current, reverse polarity
- preheat: none
- interpass temperature 150°F ,maximum
- post weld heat treatment: none
- welding data:

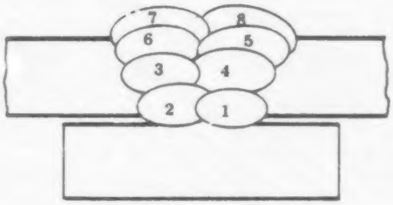


PASS NO.	WELDING PROCESS	ELECTRODE DIAMETER	CURRENT RANGE	ARC VOLTAGE
1&2	SMA	1/8	100-110	22-23
remainder	SMA	5/32	120-150	24-25

Figure 28-2-8
Sample SMA Welding Procedure
(Sheet 1 of 2)

Techniques

- position: flat (rotate with positioner to maintain flat position)
- bead technique: stringer bead
- sequence: per sketch # 2



- arc length: as short as practicable during welding and weaving shall be held to a minimum.
- angle of electrode: the electrode shall be inclined 15^0 to 20^0 from the perpendicular in the direction of travel during the complete welding operation (backhand technique)
- grinding: all starts and stops shall be ground to a minimum 1000 rms finish and the edges of the weld shall blend smoothly into base metal.
- interpass cleaning: hand slag pick and wire brush. Remove all visible slag.

Procedure

- detergent clean parts to remove any oil, chips, dirt or scale; water rinse.
- fit-up per sketch #1
- weld passes 1 and 2
- liquid penetrant test root
- weld passes 3 through 8
- grind
- liquid penetrant test final surface
- radiograph completed weld

Figure 28-2-8

Sample SMA Welding Procedure
(Sheet 2 of 2)

Application

The shielded metal arc welding process can be used for welding most of the alloys employed in a nuclear power plant. It is used most extensively for joining various types of steels, including the stainless steels, and for joining nickel alloys. It is used less extensively for joining copper and aluminum alloys. Shielded metal arc welding can be used in all positions and is, therefore, frequently used where the weld joint cannot be rotated and where it is either impractical (due to space limitations) or uneconomical to set up equipment for other electric arc welding processes.

Characteristic Defects and Their Causes

Defects most likely to occur from shielded metal arc welding are listed in Table 28-2-4 along with their probable causes and means of detection.

The shielded metal arc welding process can give all the defects associated with the oxyacetylene welding process and the additional defects of slag inclusions, weld spatter and arc strikes. The slag produced by the electrode coating normally floats on the weld puddle and is removed by interpass cleaning. Such slag can become entrapped if insufficient energy is applied to give time to float the slag or if physical recesses are created by excessive weaving, improper bead sequencing or improper electrode angle. Weld spatter always occurs with SMA but is exacerbated by improper arc length or excessive current. Arc strikes can result in localized hard spots which can initiate cracks. Spatter and arc strikes are removed by grinding.

Table 28-2-4

Characteristic Defects for Shielded Metal Arc Welding

DEFECT	PROBABLE CAUSE	DETECTABLE BY
Undercut	Improper electrode angle; insufficient number of passes	visual inspection; radiography
Burnthrough	excessive current; electrode diameter too large (excessive heating rate)	visual inspection; radiography
Porosity	improper arc length; moisture in electrode coating; foreign particles (dirt)	surface: liquid penetrant or magnetic particle subsurface: radiography
Slag Inclusion	excessive weaving; improper bead sequence; current low for electrode diameter; inadequate interpass cleaning	radiography
Incomplete Fusion	current too low; excessive weaving	radiography or ultrasonic testing
Crack in the Weld Metal	excessive current; incorrect base metal; incorrect filler material; moisture in electrode coating	surface: liquid penetrant or magnetic particle subsurface: radiography or ultrasonic
Underbead Crack	Excessive current; insufficient preheat	radiography or ultrasonic
Spatter	some spatter will occur; excessive spatter is caused by improper arc length, excessive current or improper voltage	visual inspection or radiography
Arc strike (a burn on base metal from an electric arc)	erroneously striking coated electrode against base metal; dirty ground cable connection; frayed insulation permitting cable to arc against work piece	visual inspection

In addition to slag, the electrode coating introduces a new potential source of defects. Many alloys crack when subjected to hydrogen, stress, and temperature. To prevent hydrogen induced cracking, certain electrode coatings are constituted such that very little hydrogen exists in the shielding gases. Electrodes of this type are low hydrogen electrodes. However, electrode coatings absorb moisture from the atmosphere which decomposes into hydrogen and oxygen in the electric arc. Such moisture can cause both porosity and cracking in the weld metal.

Two precautions are taken to prevent porosity and cracking from moisture in electrode coatings. First, the electrode manufacturer bakes the electrodes to dry them and packages the baked electrodes in hermetically sealed containers. Secondly, weld shops bake low hydrogen electrodes shortly before use to drive out any absorbed moisture.

TECHNIQUES FOR COMPLIANCE CHECKS

Verbatim compliance with welding procedures increases the probability of making defect free weldments. To help assure verbatim compliance. QA/QC Technicians frequently observe welding in progress to determine if requirements are being met. Methods of checking welding requirements for fuel flame and electric arc welding processes are listed in Table 28-2-5.

Table 28-2-5 should be used in conjunction with the Procedures in this module. It is intended to offer basic methods for monitoring welding variables but not intended as an inspection procedure. Later modules of this course will describe the inspection of welding typically performed by QA/QC Technicians.

Table 28-2-5

Methods of Checking Welding Requirements

TYPE OF REQUIREMENT	METHOD OF CHECKING
Joint Design and Fit Up	Compare sketch of drawing referenced by welding procedure to the physical configuration of the weld joint. Measure required dimensions with mechanical measuring devices.
Base Metal Identification (Including Backing)	Compare marking on base metal with welding procedure requirements. If unmarked, compare material issue record entries with weld procedure requirements.
Filler Material Identification	Compare marking on filler material and physical appearance and size of filler material with weld procedure requirements.
Welding Position	Compare physical position of weld joint to weld procedure requirement.
Cleanliness	Visually observe for scale, oxides, dirt, oil, etc. Compare with welding procedure requirements.
Preheat and Interpass Temperature	For preheat, measure base material temperature within one inch of the weld joint with temperature indicating device (e.g., temperature melting crayons, contact pyrometer, thermocouple.) For interpass temperature, measure the weld joint temperature immediately prior to commencement of welding.
Gas Pressure	Compare gas pressure meter readings with weld procedure requirement.
Gas Flow	Compare gas flow meter readings with weld procedure requirement.
Nature of Oxyacetylene Flame	Visually observe flame through welder's goggles or hood; compare with weld procedure requirement.

Table 28-2-5 (Cont.)
Methods of Checking Welding Requirements

TYPE OF REQUIREMENT	METHOD OF CHECKING
Welder's Techniques (Bead, Forehand, Backhand, Angle of Electrode, Progression, Interpass Cleaning, Grinding, Back Gouging)	Visually observe the welder's practices; compare with welding procedure requirements.
Current Type and Polarity	Observe switch settings on the electrical power supply for AC or DC and straight or reversed; compare with welding procedure requirements.
Current	Read value or ammeter on power supply or clamp tong ammeter around one cable and read value (Note: welding must be in progress to read current or voltage); compare with welding procedure requirement.
Voltage	Read value on voltmeter on power supply or clamp tong voltmeter around one cable and read value; compare with welding procedure requirement.
Postweld Heat Treatment	Compare time-temperature chart with welding procedure requirement; ensure the chart represents the weld joint being checked.

EXERCISES

1. Enter specific instructional information on the oxyacetylene welding procedure outlined below and indicate for each entry whether it is an essential or nonessential variable:

Oxyacetylene Welding Procedure Outline	Instruction to Welder	Essential Nonessential
a. Joint Design		
b. Base Metal Type		
c. Filler Metal Type		
d. Welding Position		
e. Preheat (yes/no)		
f. Postweld Heat Treatment (yes/no)		
g. Fuel Gas		
h. Nature of Flame		

2. Complete the chart below by entering the probable cause of each defect from the oxyacetylene welding process and the inspection method capable of detecting the defect. More than one probable cause may be listed.

DEFECT	PROBABLE CAUSE	INSPECTION METHOD
a. surface cracks		
b. Incomplete fusion		
c. undercut		

3. For each application described below, list the minimum inspection to be made of the completed weld.

APPLICATION	MINIMUM INSPECTIONS
a. Oxyacetylene welding of a V-butt joint where cracks and underbead cracks are the only defects of concern	
b. Oxyacetylene welding of a V-groove corner joint where surface cracks are the only defects of concern.	

c. Oxyacetylene hardsurfacing of a flat surface where surface porosity and surface cracks are the only defects of concern.

d. Oxyacetylene welding of a V-groove tee joint where undercut is the only defect of concern.

4. Place the letter of the probable defect beside the corresponding SMA welding condition.

SMA WELDING CONDITION	PROBABLE DEFECT
a.____moisture in electrode coating	a. slag inclusion
b.____using a copper nickel electrode to weld nickel-chrome-iron base metal	b. crack
c.____arc length too long	c. porosity
d.____excessive current during welding of the root pass	d. spatter
e.____excessive weaving	e. burn through

5. Place the following steps in proper sequence for SMA welding.

a. post weld heat treatment

b. interpass cleaning

c. fit up

d. detergent clean parts and water rinse

e. weld beads 2 through 9

f. weld root pass

g. preheat

    h. radiograph final weld
    i. grind weld contour

6. Name the source(s) of the following welding fundamentals for SMA welding:
    a. heat source
    b. shielding
    c. filler material

MATERIALS

The following materials are required to support this module.

1. Welder's Goggles or Hoods (hand held face shields are ideal)
2. Temperature Measuring Devices (crayon or contact pyrometer)
3. Lab Coat or Apron or work clothes
4. Long sleeves
5. Welded samples made by oxyacetylene and shielded metal arc processes

PROCEDURES

Safety Precautions

Students/trainees should observe the following safety precautions during any visit to a welding shop:

a. Never look at a welding flame or electric arc without welder's goggles or hoods. (Note: sunglasses are inadequate to protect the eyes from intense light from welding.)

b. Wear long sleeves and either work clothes, lab apron, or coveralls..

c. Avoid stepping on hoses and cables.

d. Do not touch or adjust welding equipment unless requested to do so by the instructor or tour guide.

e. Do not touch pieces recently welded; they will probably be very hot.

1. Visit a Welding Shop Employing Oxyacetylene Welding

On initial arrival at the welding shop, the instructor or a welding shop member will probably guide the students/trainees on a tour of the shop and explain pertinent safety rules to be observed. Subsequently, students/trainees should observe oxyacetylene welding in progress and complete Data Table 28-2-1 in accordance with this procedure.

a. Observe oxyacetylene welding in progress using Table 28-2-5 as guidance. Do not yet review the corresponding welding procedure. Complete Sections A through E of Data Table 28-2-1.

b. In completing Sections A through E, the student/trainee may need to ask questions of the welding shop tour guide to obtain necessary information. In each such case, the student/trainee should determine whether the information is made self-evident by items at the welding station other than the welding procedure. Leave blank any data point which depends solely on the welding procedure as the source of information.

c. Compare the welding procedure against the entries in Sections A through E of Data Table 28-2-1.

d. Answer the questions in Section F of Data Table 28-2-1.

2. Visit a Welding Shop Employing Shielded Metal Arc Welding

After being introduced to the shop environment, students/trainees should observe shielded metal arc welding and complete Data Table 28-2-2 in accordance with this procedure.

a. Obtain an SMA welding procedure that is in use and complete Section A of Data Table 28-2-2 from the content of the procedure using Table 28-2-5 as guidance.

b. Observe shielded metal arc welding in progress that is governed by the procedure used to complete Section A of Data Table 28-2-2 and check off each entry in Section A upon validating that the requirement is being met.

c. List in Section B of Data Table 28-2-2 any requirement that is not met. If all requirements are met, enter none.

d. Using welder's goggles or hood, observe the welder strike an electrode and burn that electrode. Answer the questions of Section C of Data Table 28-2-2 based on these observations.

e. Observe a 'stop' on the weld joint. Describe the appearance of the stop in Section D of Data Table 28-2-2.

f. If the coated electrodes are heated prior to use, observe the electrode oven and complete Section E of Data Table 28-2-2.

g. Determine if the ammeters and voltmeters are periodically calibrated for accuracy. Complete Section F of Data Table 28-2-2.

3. Compare Monitoring Techniques

   a. Discuss in class the differences in monitoring techniques between procedure #1 and Procedure #2.

   b. Identify advantages and disadvantages of each.

DATA TABLE

Data Table 28-2-1
Oxyacetylene Welding

A. Joint Design (Circle ones in use)

1. butt corner tee lap edge hardsurface

2. grooved squared

3. Backing Used: yes no

B. Base Metal

1. Material Type________________________________

2. Thickness____________________________________

3. Backing Material Type__________________________

C. Filler Material

1. (Circle one)' bare straight length rod
bare spooled rod
coated electrode
flux-cored spooled rod

2. Filler Material Type___________________________

3. Record Marking That is on the Filler Material______

D. Welding Parameters

1. Position_____________________________________

2. Preheat Temperature___________________________

3. Nature of Flame_______________________________

E. Techniques

1. Stringer or Weave Bead_________________________

2. Forehand or Backhand__________________________

3. Single or Multiple Pass__________________________

4. Distortion Control Techniques________________________

5. Initial or Interpass Cleaning Method________________

6. Reverse Side Welding: yes no

F. Evaluation

1. Is filler material compatible with base material? if not, why not?

2. Did the oxyacetylene flame being used agree with the type of flame required by the procedure?

3. Compare the remaining data entries for Section A through E with the welding procedure. Do all entries agree with the procedure? List any differences and explain why there is a difference.

4. List each data point that depended solely on the procedure as the source of information. Describe what could be done for each to make the data self-evident to the observer. (Guidance: The welding procedure describes what should be done. The observer is noting what is actually being done.

The observer should be able to determine from the nature of observed items, marking or instrumentation that what is being done agrees with what is required to be done.)

5. List each inspection required by the welding procedure and for each name the type of defects the inspection is capable of detecting

DATA TABLE 28-2-2

Shielded Metal Arc Welding

A. Procedural Requirements:

Base material type and specification number............

Welding process....................................

Manual or machine..................................

Position of welding................................

Filler metal specification number..................

Filler metal classification........................

Single or multiple pass............................

Welding current (AC or DC).........................

Polarity...

Welding progression................................

Cleaning...

Root Treatment.....................................

Grinding (other than root).........................

Preheat and interpass temperature..................

Post weld heat treatment...........................

Welding Data

Pass No.	Electrode Size	Welding Current		Electrode Angle	Sketch the Joint Detail
		Amperes	Volts		

Inspections (enter "none" if none are required)

1. Root ______________________________
2. Intermediate layers ______________________________
3. Final weld ______________________________

B. Differences between requirements and practice:

Requirements Not Met	Actual Practice

C. Observation of electrode arc and weld puddle.

1. Describe how weld arc length was maintained. List observed effects of differences in arc length.

D. Appearance of welding stop
    1. Contour ______________________________
    2. Pits ______________________________

E. Electrode Oven
    1. Are electrodes segregated by type ____________
    2. How is it known how long the electrodes have been in the oven.

F. Calibration Data

	Ammeter	Voltmeter
series number		
frequency of calibration		
date of last calibration		
due date for calibration		

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, The American Society of Mechanical Engineers

ASME, Boiler and Pressure Vessel Code, Section IX, Welding and Brazing Qualifications, The American Society of Mechanical Engineers

AWS, D1.1, Structural Welding Code, American Welding Society, Inc.

AWS, D1.2, Commentary on Structural Welding Code, American Welding Society, Inc.

ACROS, Welding Products, Pamphlet GC 47260, Acros Corporation, 1500 South 50th Street, Philadelphia, PA 19143

TEST

1. State the function of the following equipment used in oxyacetylene welding:
    a. torch

    b. pressure regulations

    c. needle valves

    d. bare rod

2. Name three types of oxyacetylene flames, describe how each is obtained, and how each is visually discernable.

3. Describe how an oxyacetylene welder controls the size of molten weld puddle.

4. Arrange the following steps of an oxyacetylene welding procedure into correct sequence.
    a. radiograph
    b. detergent clean and rinse
    c. weld root
    d. preheat
    e. weld subsequent passes
    f. fit-up

5. What is the type of fuel gas considered an essential variable of the oxyacetylene welding process?

6. State one probable cause of each of the following defects in a weld made by the oxyacetylene welding process:
   a. porosity
   b. underbead crack
   c. incomplete fusion

7. State the function of the following equipment used in the shielded metal arc welding process.
   a. electrode holder

   b. power source

   c. ground clamp

8. Name three functions of the coated electrode used in shielded metal arc welding.

9. Relate the terms "straight polarity" and "reverse polarity" as applied to shielded metal arc welding.

10. Why does the shielded metal arc welder attempt to maintain constant arc length?

11. Why is the type of electrode an essential variable in the shielded metal arc welding process?

12. State one probable cause of the following defects in a weld made by the shielded metal arc welding process.
    a. undercut

    b. porosity

    c. slag inclusion

    d. excessive splatter

NUCLEAR TECHNOLOGY

MODULE 28-3

TUNGSTEN INERT GAS (TIG), METAL INERT GAS (MIG), AND SUBMERGED ARC WELDING

COURSE 28 WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
⇨ MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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INTRODUCTION

The Nuclear QA/QC Technician monitors welding operations and inspects completed welds. In addition, the technician determines if correct welding procedures are in use and that the assigned welders are properly qualified. In carrying out these tasks, the technician relies upon knowledge of welding technology as well as written procedures and instructions. This module describes the technology associated with the tungsten inert gas, metal inert gas, and submerged arc welding processes.

Tungsten inert gas, metal inert gas and submerged arc welding processes are readily automated and offer a wide range of welding speeds and depth of base metal melting. While the equipment is somewhat expensive, lower welding costs may be realized due to their higher welding speeds, as compared to oxyacetylene and shielded metal arc welding.

The tungsten inert gas welding process enjoys the most versatility, but has the slowest welding speed of these three processes. It can be used with all types of metals and in all positions. It offers excellent control of heating rate and resultant base metal penetration.

The metal inert gas welding process offers much higher welding speeds and it is suitable for welding all types of materials in all positions. Highest welding speeds are attainable in the flat and horizontal positions.

Submerged arc welding has the largest range of selection of weld bead size and penetration depth. It is employed primarily in welding low carbon and low alloy steels and for hard-surfacing. Its welding speed is unsurpassed by any of the other welding processes covered in this course, but flat or horizontal positions must be used.

This module describes the key features of each of these welding processes. It presents the apparatus, process techniques, procedures, applications, associated defects and inspections for each process. The student/trainee should approach this module from the viewpoint of how each welding process makes (or fails to make) a sound weld. It will become evident that each process contains key features which if employed properly can produce high quality weldments.

Knowledge of the welding processes presented in this module should equip the student/trainee to understand the basis for qualifications, process controls and inspection requirements presented in later modules of this course.

MODULE PREREQUISITES

Prior to commencing study of this module, the student/trainee should have prior training or experience in welding fundamentals, oxyacetylene welding and shielded metal arc welding.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Label sketches of equipment to name the major components for TIG, MIG and SAW welding processes.
2. Describe the functions of major components of the equipment used in TIG, MIG and SAW welding processes.
3. State the effect on TIG, MIG, and SAW welding processes of changes in procedure variables including voltage, current, feed rate, and travel speed.

4. Describe the shielding employed with TIG, MIG and SAW welding processes.
5. Name and describe the three methods of metal transfer in the MIG welding process.
6. Name at least one potential cause for given weld defects in any of the TIG, MIG and SAW welding processes.
7. Name three functions of the flux used in SAW welding processes.
8. Name two typical applications each of the TIG, MIG and SAW welding processes and describe the features of the process which make it suitable for the named application.

SUBJECT MATTER

TUNGSTEN INERT GAS WELDING PROCESS

Description of Process

The tungsten inert gas welding process uses a non-melting tungsten electrode. The welding arc is struck between the electrode and the work piece and produces the heat necessary for welding. A forced flow of inert gas shields the end of the electrode, the arc, and the molten weld puddle from the atmosphere. Filler material is added separately into the arc.

Equipment

The tungsten inert gas (TIG) welding process employs a nonconsumable electrode, electrode holder (torch), electrical power supply and a shielding gas supply as shown in Figure 28-3-1.

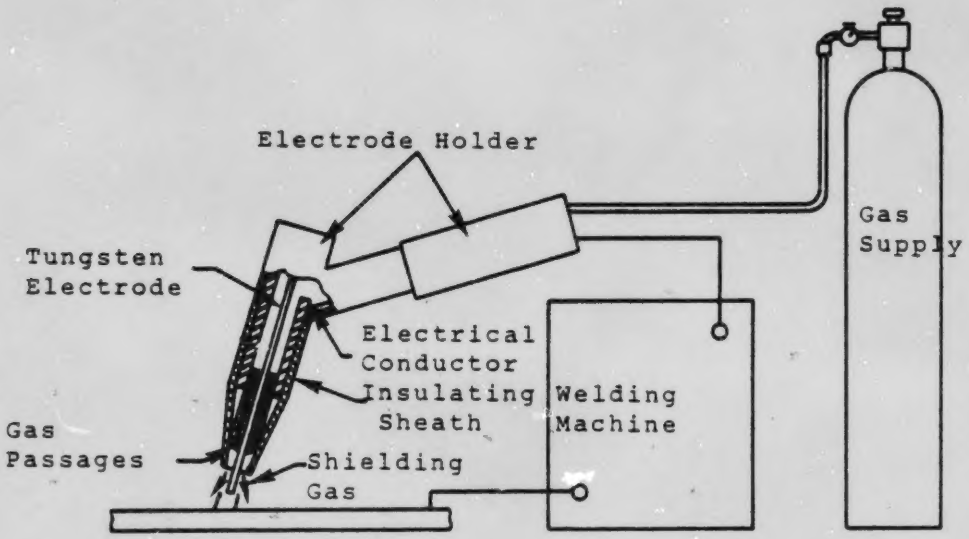
Electrode Holder
Gas Supply
Tungsten Electrode
Electrical Conductor
Insulating Sheath
Welding Machine
Gas Passages
Shielding Gas

Figure 28-3-1

Schematic Diagram of Gas Tungsten-Arc Equipment

The electrode may be pure tungsten or a tungsten-alloy. Tungsten alloy electrodes contain one or two percent thorium or zirconium to improve arc initiation and stabilization. The electrodes range in diameter from .020 inch to .250 inch and are about seven inches long. The electrode diameter is selected to correspond to the welding current to provide the desired current density at the tip.

The torch receives the electrical power supply cable and the shield gas hose. Electrical power is conducted to the electrode and the shielding gas is routed around the electrode. A shielding gas cup surrounds the electrode and channels gas flow to displace the atmosphere around the arc. The electrode sticks out slightly past the shield gas cup to permit arc initiation. Some TIG torches are equipped to be water cooled.

The electrical power supply provides direct or alternating current. Power supplies used for SMA welding may be used for TIG welding or power supplies may be designed specifically for use with TIG welding. Power supplies designed for TIG welding are equipped with automatic means for controlling gas and water flow at the start and stop of welding. A high frequency current is often superimposed for arc initiation and stabilization.

Argon or helium is normally the shielding gas, although an argon/helium mixture is occasionally used. These inert gasses do not combine with other elements and are relatively insoluble in molten metals. Gas purity is normally 99.95 percent or more to insure excellent shielding.

Process Techniques

The TIG process requires some preliminary means of initiating emission of electrons and ionization of shielding gas. The arc can be initiated by touching the electrode to the work piece or to a copper starting block and quickly withdrawing it to form an arc. Another means is high frequency arc initiation. Use of the high frequency spark or the copper starting block eliminates the chance of breaking off the tip of the electrode and imbedding it in the weld.

In the TIG welding arc, the negative ions (electrons) have more effect than the positive ions, apparently due to the high speeds acquired by the electrons in moving through the arc. For this reason, straight polarity is preferred whenever direct current is used. With straight polarity, the electrons emitted from the negative electrode are accelerated by arc voltage and strike the positive work piece at high speeds. This direction of electron flow results in the majority (about 2/3) of arc energy being deposited in the base metal. If reversed polarity is used, electrons striking the electrode result in the majority of arc energy being deposited in the electrode with less penetration in the work piece.

Argon requires less arc voltage than helium to sustain the arc and it gives a smoother, quieter arc. These properties make argon especially suited for TIG welding of thin parts and for welding in the overhead and vertical positions. On the other hand, the higher arc voltage of helium is desirable for welding thick joints. Also, the higher arc energy of helium permits higher welding speeds. Where a balance of characteristics is desired, a mixture of argon and helium is used.

The flow of gas around the electrode shields the molten weld puddle from the atmosphere. The gas cup and the heat from the arc give about the same gas flow pattern, whether argon or helium is used. However, slightly higher flow rates are needed with helium for good shielding due to helium's lower atomic weight.

Continuous current or pulsed current may be used for

TIG welding. Pulsed current permits higher instantaneous arc energy, which rapidly melts base metal and filler material during the pulse. Between pulses of current, no heat is applied. The net result is deeper melting but smaller aggregate size of molten weld metal. Advantages of pulsed current are:

- increased depth to width ratio of weld beads - This ratio increases with decreases in pulse duration coupled with increases in current value.
- elimination of burn through - Complete melting of the root will occur but the molten weld puddle is too small to fall away.
- minimal heat affected zone - Dissipation of heat between pulses reduces the volume of base metal whose properties are affected by heat from welding.
- agitation of the weld puddle - Electromagnetic forces tend to agitate the weld puddle. These forces are larger because of the large current value associated with pulsed current. Agitation of the weld puddle reduces the chances of porosity and incomplete fusion.

If filler material is needed, straight length of spooled bare rod is used. Best control of weld puddle flow is normally obtained with the forehand technique. Automated TIG welding uses spooled bare rod to permit continuous feed of filler materials into the arc. As with other arc welding processes, the filler material feed rate must be compatible with the arc energy available for melting the filler material.

Unique Techniques

Automated TIG welding machines may be set for stringer bead or weave bead techniques. When employing the weave bead technique, equipment oscillation controls are adjusted for desired oscillation width, frequency and dwell time.

(Dwell time refers to time of no lateral movement of the torch at either extreme of bead width.) Dwell time permits longitudinal progression of the torch (or work piece), such that the next oscillation provides proper bead overlap at the extremes of the weld bead width.

Procedure Variables

Welding procedures for the tungsten inert gas welding process cover the variables listed in Table 28-3-1. Procedures will specify specific values for each variable listed.

The procedure variables listed in Table 28-3-1 are divided into essential and nonessential variables using the same rationale as used for other welding processes. That is, essential variables are those so important as to require procedure requalification when any essential variable is changed beyond limits specified by the applicable welding code. Values for nonessential variables must be provided to the welder but those values can be changed by engineering without requalifying the procedure.

The TIG process may employ multiple electrodes. Each TIG welding procedure should identify the type of electrode (e.g., tungsten, tungsten-thorium), the number and spacing of electrodes and the length of electrode extension beyond the face of the gas cup. The procedure may also specify the electrode tip preparation and the frequency of repreparing the electrode tip.

While the procedure should cover initial and interpass cleaning, little interpass cleaning is necessary with TIG welding. There is no slag and, if shielding is good, no oxides.

FUNDAMENTAL VARIABLES	ESSENTIAL VARIABLE	NONESSENTIAL VARIABLE
Joint Design	None	(a) groove type and design (b) use of backing
Base Metals	(a) material type (b) joint thickness	None
Filler Material	(a) type of material (b) Chemical composition of weld metal (c) use of consumable inserts	(a) diameter of filler (b) electrode type and diameter
Position	(a) where impact properties are tested, the welding position to be used	(a) for all other applications the welding position to be used
Preheat	(a) decrease of more than 100 F in minimum preheat temperature from that qualified (b) where impact properties are tested, an increase in specified maximum interpass temperature	(a) minimum preheat temperature (b) maximum interpass temperature
Post Weld Heat Treatment	(a) heat treatment temperature and time	None
Gas	(a) type of shielding gas	(a) gas flow rate (b) use of gas backing
Electrical Characteristics	(a) where impact properties are tested, type of current and voltage	(a) where impact properties are not tested, type of current and polarity and value of current and voltage
Technique	(a) where impact properties are tested, oscillation width, frequency and dwell times; number of passes; use of single or multiple electrodes; and vertical progression	(a) use of oscillation and oscillation settings (b) gas cup size (c) method of initial and interpass cleaning (d) method of back gouging (e) number of passes (f) number of electrodes (g) use of nonmetallic retainers (h) electrode spacing (i) vertical progression (j) manual or automatic

Application

Tungsten inert gas is a very versatile welding process that can be used for all alloys and in all positions. It is very capable of producing welds free of porosity and oxides or nitrides. It offers excellent control of welding heat, depth of penetration, and weld bead shape. There is no spatter or slag. TIG weld bead surfaces are relatively smooth and uniform. Therefore, manual and automatic TIG weld bead surfaces are relatively smooth and uniform. Therefore, manual and automatic TIG welding have a wide variety of applications.

TIG is particularly useful for welding very thin parts and root passes of thicker parts. Its precise heat control permits such application without risk of burnthrough and there is no slag to be trapped in root areas. When finish of the as-welded bead surface is important, TIG makes an excellent selection of welding processes.

The main drawback of TIG welding is its relatively slow welding speed. Therefore, it is not frequently used for welding heavy gauge materials (except for root passes).

Characteristic Defects, Causes and Detection

Tungsten inert gas welding can produce the defects listed in Table 28-3-2.

As shown in Table 28-3-2, the causes of porosity are mostly associated with inadequate shielding. In addition to improper shield gas flow, arc wander can cause porosity in TIG welding. Electromagnetic forces generated by current can divert the arc momentarily or continuously. This phenomenon stems from a physical law that charged particles moving through a magnetic field will tend to go in a direction at right angles to the magnetic field. Weld joint configurations and residual magnetism can cause the arc to see differing magnetic fields as weld progression occurs and the arc will wander. The welder will notice arc wander and eliminate it by shifting the ground cable connection or demagnitizing the work piece. Where the arc has wandered outside the shielding gas envelope, porosity will occur and the welder should grind such areas to sound metal.

Arc wander can also cause incomplete fusion because the heat is diverted from the desired area. Again, the welder should notice arc wander and grind as necessary to avoid incomplete penetration in the final weld.

When tungsten inclusions are found in the weld, the obvious source is the TIG electrode. The electrode has been struck on the work piece or dipped into the weld puddle or melted from excessively high current. When the welder notices dipping of the electrode, welding should be stopped and the area should be ground.

Weld metal cracks can be caused by using incorrect base or filler material and by incorrect weld bead shape. As the weld bead solidifies, shrinkage will cause surface tension if the bead is restrained from shrinking. As shown in Figure 28-3-2, concave beads place surfaces in tension while convex beads do not.

Weld metal cracks caused by concave weld beads can be avoided by proper combination of travel speed and filler material feed rate such that a slightly convex weld bead is produced.

Another area where weld bead convexity can cause cracking is at the point where welding of a bead is stopped. If the arc is rapidly withdrawn to extinguish welding, a weld bead crater results. The convex crater creates tension which tends to crack the weld metal. Such crater cracks are pictured in Figure 28-3-3.

Crater cracks can be avoided by a gradual withdrawal

Table 28-3-2

Characteristic Defects with TIG Welding

DEFECT	CAUSE	DETECTABLE BY
Porosity	(a) flow of shielding gas too low (b) flow of shielding gas too high such that turbulence draws in air (c) air drafts blowing shield gas away (d) gas supply hose, fittings or gas passages in torch are blocked (e) arc wander	(a) welder should notice black oxides forming (b) liquid penetrant for porosity open to survace (c) radiography for subsurface (d) welder should notice arc wander
Incomplete Fusion	(a) current too low (b) travel speed too high (c) filler material feed rate too high (d) arc wander	(a) welder should notice arc wander (b) radiography or ultrasonics
Tungsten Inclusion	(a) striking the arc on the work piece (b) dipping the electrode into the weld puddle (c) current too high for electrode diameter	(a) welder should notice deterioration of electrode tip (b) radiography
Weld Metal Crack	(a) incorrect base metal type (b) incorrect filler material type (c) concave weld bead (d) crater cracks	(a) liquid penetrant or magnetic particle for cracks open to surface (b) radiography or ultrasonics for subsurface cracks

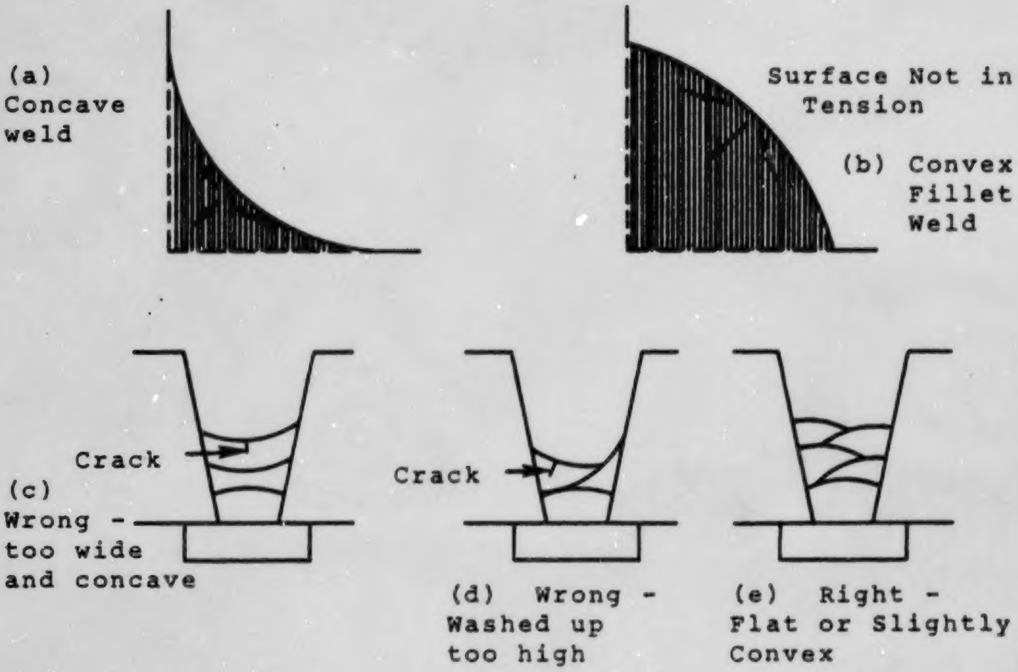
(a) Concave weld
Surface Not in Tension
(b) Convex Fillet Weld
Crack
(c) Wrong - too wide and concave
Crack
(d) Wrong - Washed up too high
(e) Right - Flat or Slightly Convex

Figure 28-3-2
Concave and Convex Weld Beads

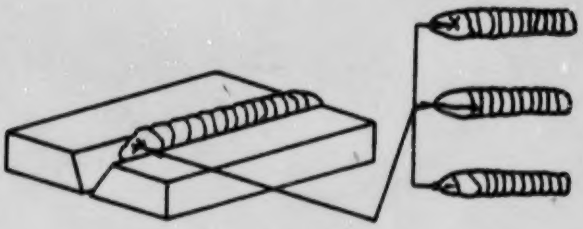

Figure 28-3-3
Crater Cracks

of the arc with sufficient filler material addition to fill up the crater. In this manner, the welding stop is convex rather than concave. Just to make sure there will be no crater cracks in the final weld, welders often grind each stop to remove the crater. It is noted that crater cracks can also occur with any welding process.

METAL INERT GAS WELDING PROCESS

Description of Process

Metal inert gas welding (MIG) is a process that produces fusion by heating with an electric arc between a consumable electrode and the work piece. Shielding is provided by gas flow around the consumable electrode. Fill material is provided by the consumable electrode.

Equipment

Four basic components comprise the metal inert gas welding equipment: welding torch or gun, wire feeder and wire supply, welding power source, and shielding gas supply. These components are schematically pictured in Figure 28-3-4.

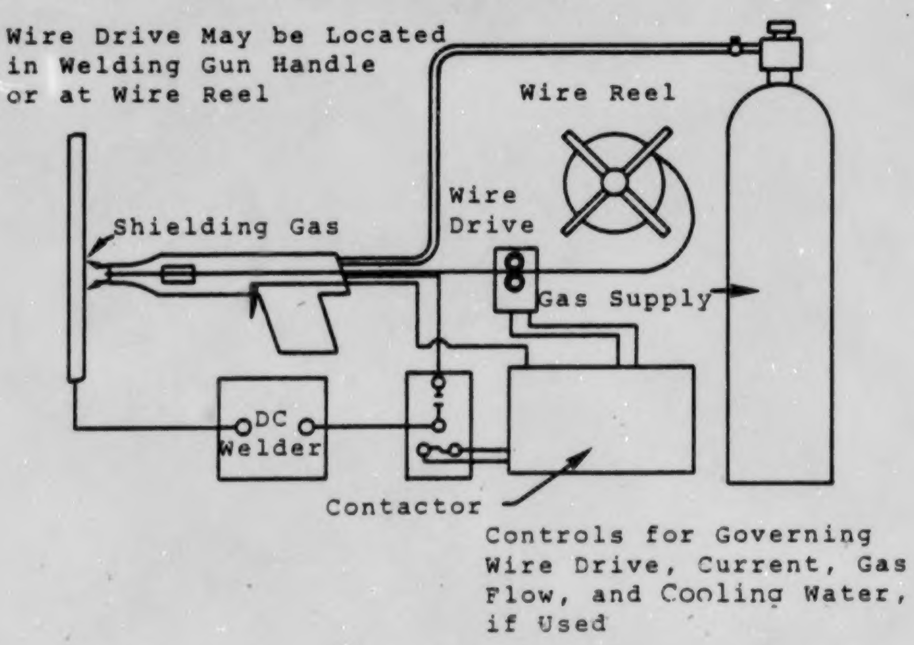
Wire Drive May be Located in Welding Gun Handle or at Wire Reel
Wire Reel
Wire Drive
Shielding Gas
Gas Supply
DC Welder
Contactor
Controls for Governing Wire Drive, Current, Gas Flow, and Cooling Water, if Used

Figure 28-3-4

Schematic Diagram of Gas Metal-Arc Welding Process

Electrical contact with the bare filler wire is made in the torch such that the filler wire becomes a consumable electrode. Shielding gas enters the torch and envelopes the wire as it exits. The bare filler wire is melted by the electric arc at a rate equal to the feed rate. If the torch is operating at over 200 amps it is normally water cooled.

The torch is adaptable to automatic welding or manual semi-automatic welding. In automatic MIG welding, a central panel controls the entire welding sequence. The central control panel (1) initiates gas flow, cooling water flow, wire feed and travel carriage speed, (2) maintains arc length, current, travel speed, gas flow, etc., to keep stable welding conditions during the welding cycle, (3) stops travel carriage; starts crater fill; stops welding current, gas flow and cooling water, and (4) returns carriage to starting position.

In manual semi-automatic MIG welding, a hand held torch employs a trigger switch to activate welding. It may or may not be water cooled. Some manual torches have an integral wire drive which "pulls" the wire. Use of a "pull" gun with a remote wire feeder permits welding with very fine wires.

Spooled bare rod is fed by a motorized wire feeder. The wire feeder may be separated from the torch or integral with it. Rollers and guide tubes keep a straight feed through the torch. The spooled wire may be solid or flux-cored.

Direct current power supplies are designed specifically for MIG welding. Early versions of MIG power supplies work on a constant current principle. With these power supplies, voltage varies inversely with changes in current. For a given current setting, if wire feed rate is slightly high, arc length is decreasing which decreases voltage. The voltage decrease is sensed by the wire feeder and the feed rate is automatically slowed. If feed rate is too slow, arc length is increasing which raises voltage. The wire feed sensor detects the voltage increase and increases feed rate. In later MIG power supply designs, constant or rising voltage principles are employed. The wire feeder maintains a preset speed and arc length is controlled by the power supply. If arc length decreases, the current output of the power supply increases to maintain constant (or rising) arc voltage. The increased current melts the wire at a faster rate which increases arc length. As arc length increases, current decreases to maintain constant (or decreasing) arc voltage. Decreased current lowers the melting rate of the filler wire.

Argon or helium shielding gas is used for MIG welding of aluminum, copper, titanium, magnesium, and zirconium alloys. For low carbon and low alloy steels, either carbon dioxide or argon with up to 5% oxygen is used.

The MIG welding process can employ either of two methods of transferring filler material into the weld puddle: arc metal transfer or short circuiting transfer. Arc metal transfer may be by a spray of very fine droplets or by globular droplets.

Spray Arc Transfer Technique

In the spray arc transfer method, very tiny droplets of molten filler material travel across the arc from the bare wire electrode to the work piece. As bare wire is fed into the arc, the arc energy melts the wire at a rate which keeps arc length essentially constant and keeps a continuous spray of filler material droplets. Electron and gas ion flow is the same as in tungsten inert gas welding (TIG). Unlike the TIG process, however, the MIG electrode is constantly spraying droplets into the weld puddle and there is a reversal in the effects of polarity.

The positive gas ions give the largest effect in the MIG spray arc transfer method. With direct current straight polarity, positive ions move toward the negative electrode and against the spray of droplets. Consequently, the droplets are slightly larger before being released into the arc stream and they strike the work piece with less velocity and penetrating power. With direct current, reversed polarity, the positive gas ions move toward the negative work piece and with the spray of droplets. Consequently, smaller droplets are released and gain more speed in traversing the arc and strike the weld puddle with more penetrating power. The spray arc transfer method works best on direct current reversed polarity.

The MIG spray arc transfer process was initially developed in welding of aluminum alloys using argon or helium shielding gas. But when this process was applied to steels, considerable arc wander deteriorated the stable conical arc spray pattern associated with aluminum welding. Apparently, oxides on steel surfaces gave resistance to arc penetration and the arc wandered in search for the easiest path of penetration. Undercut and porosity resulted.

MIG spray arc has been quite successfully applied to welding of steels by adding small quantities of oxygen or carbon dioxide to argon. Addition of these oxidizing agents produce a fairly uniformly oxidized surface such that the arc becomes anchored in the immediate vicinity of the arc crater. Since the oxidizing agents can cause porosity and scavenge some of the alloy ingredients of the base metal and filler material, deoxidizers and/or alloying ingredients need to be added. Consequently, filler wires containing deoxidizers are used for MIG welding of steels.

Shielding with 100% carbon dioxide in MIG welding of steels permits higher welding speeds and greater penetration. The chief drawback to use of this less expensive gas is a rather harsh arc and considerable spatter. These drawbacks are overcome by using filler wire containing deoxidizers and addition of fluxes. Flux can be added in the form of magnetic powders which are attracted to the wire in the torch and form a thin coating that is carried into the arc. A more popular method is flux-cored wire where tubular wire is filled with flux. In either case, the flux contains deoxidizers to minimize porosity and allow metals to achieve desired weld metal chemistry.

Globular Arc Transfer Technique

If the high current density needed for spray arc metal transfer is reduced, an abrupt change in the transfer mode occurs at some point designated as the transition current. For a given diameter electrode operating in the spray arc mode and as current is decreased, the size of the tiny droplets gradually increases and the number of drops per second gradually decreases. At the critical current, the droplets suddenly become much larger and drop much less frequently. This is illustrated for mild steel in Figure 28-3-5.

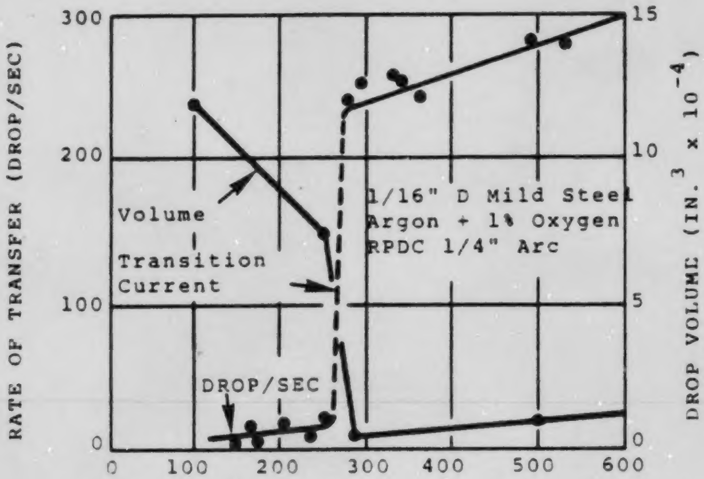

Figure 28-3-5
Current (Amperes)

Graph showing relationship of amperage to droplet transfer rate and drop size for welding with 1/16 in. dia. steel wire and argon shielding.

The curves in Figure 28-3-5 illustrate for this case that, as current decreases from 265 amperes to 255 amperes, the drop size increases from .04 inch to .16 inch and the drop rate decreases from 240 drops per second to 15 drops per second. The median current at which these abrupt changes occur is 260 amperes which is the transition current value in this case. The same transition phenomenon occurs with all metals but at different levels of current. However, the electrode melting rate does not abruptly change but follows the expected change proportional to the change in current.

Below the transition current globular metal arc transfer occurs. Since there are insufficient forces within the arc to "jet" spray the filler metal, a ball of molten filler metal hangs to the electrode tip until it is large enough to be pulled away by gravity. Globules larger in diameter than the wire diameter are not uncommon.

Globular arc transfer gives less penetration than spray arc transfer and causes arc turbulence and weld spatter. Accordingly, spray arc transfer is more commonly used.

Short Circuiting Metal Transfer Technique

Short circuiting metal transfer occurs by frequently dipping the electrode into the weld puddle. This method operates with current values well below the transition current and it requires special circuits in the power supply to limit short circuiting current slope and peak. The short circuiting method is illustrated in Figure 28-3-6.

Starting with the electrode shorted to the weld puddle in Figure 28-3-6, the arc is extinguished and a surge of current is caused by the short circuit. The power supply limits the rate of current increase and the current peak to avoid overloading the electrical circuitry. When the electrode withdraws from the puddle, ample current flow exists to recreate the arc. Heat from the arc forms a globule on the wire tip by the time the wire again dips into the weld puddle starting the cycle again. All filler metal transfer occurs when the arc is extinguished during the short circuit which is occuring at a steady frequency anywhere from 20 to over 200 times per second. The net result is a very stable arc of low energy and heat input. Short circuiting metal transfer produces a relatively small weld puddle and much less penetration as compared to spray arc transfer. Any of the shielding gases used with spray arc may be used.

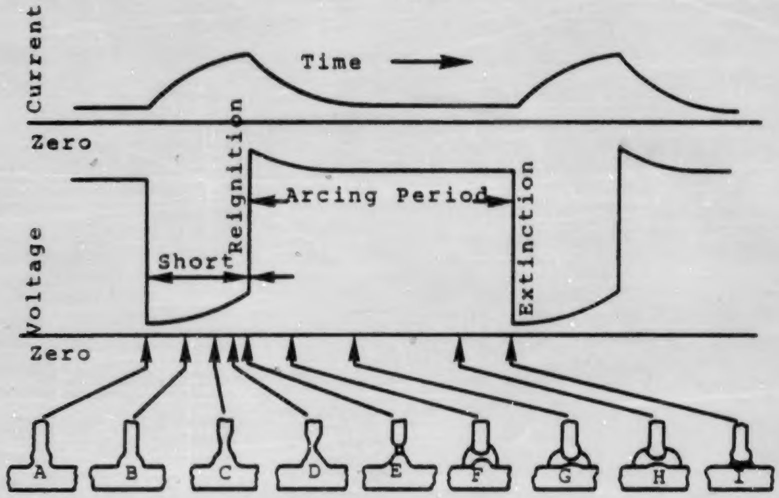

Figure 28-3-6

Oscillograms and Sketches of Short Circuiting Arc Metal Transfer

Procedures

Metal inert gas welding procedures should cover the variables listed in Table 28-3-3. Procedures specify specific values for each variable listed.

The rationale for differentation of essential and non-essential variables is the same as that described for the TIG welding process.

As with tungsten inert gas welding, the MIG welding process can employ multiple electrodes and oscillation controls. The welding procedure will specify the various equipment settings needed for automatic or manual welding. Most welders make it a standard practice to check the operation of the equipment by welding a small test piece prior to commencing production welding. This helps to assure proper alignment and setting of variables.

Application

Metal inert gas welding is suitable for all types of base metals. The various methods of filler metal transfer permit MIG welding in all positions.

Spray arc MIG welding gives deep penetration and it offers welding speeds four or more times the speed of shielded metal arc welding. Travel speeds of 30 inches per minute and deposition rates of 20 pounds per hour are not uncommon. Therefore, spray arc MIG welding is frequently employed where large volumes of filler metal is needed to complete the weld. Due to the relatively large size of the molten weld puddle, spray arc is suited for flat and horizontal positions.

Short circuiting metal transfer permits MIG welding to be accomplished in the vertical and overhead positions due to the smaller molten weld puddle associated with this method. Also, it is used for welding thin materials since its lower heating rate eliminates burnthrough that would occur with spray arc.

Characteristic Defects, Their Causes and Detection

Characteristic defects, their causes and means of detection for MIG welding are given in Table 28-3-4.

Defect prevention with MIG welding primarily rests with obtaining the correct combination of weld metal deposition rate and travel speed. Current values needed for MIG welding are dependent on diameter of bare filler

Table 28-3-3
Procedure Variables for Metal Inert Gas Welding

FUNDAMENTAL VARIABLES	ESSENTIAL VARIABLE	NONESSENTIAL VARIABLE
Weld Joint	None	(a) groove type and design (b) use of backing
Base Metals	(a) material type (b) joint thickness	None
Filler Material	(a) type of material (b) chemical composition of weld material (c) whether bare solid wire or bar flux-cored wire	(a) diameter of wire
Position	(a) where impact properties are tested, vertical progression if vertical position is used	(a) the welding position to be used
Preheat	(a) decrease of more than 100 F in minimum pre-heat temperature from that qualified an increase in specified maximum interpass temperature	(a) minimum preheat temperature (b) maximum interpass temper-ature (c) whether preheat is to be maintained to stress relieve furnace
Post Weld Heat Treatment	(a) heat treatment time and temperature	None
Gas	(a) a change in type of shielding gas or gas mixture	(a) type of shielding or gas mixture (b) gas flow rate (c) use of gas backing
Electrical Characteristics	(a) where impact properties are tested, the type and polarity of current and values for voltage and current	(a) current type and polarity (b) current and voltage values (c) type of power supply (d) method of metal transfer
Technique	Where impact properties are tested: (a) width, frequency and dwell time of oscillation controls (b) number of passes (c) number of electrodes (d) vertical progression	(a) whether stringer or weave bead (b) method of initial and interpass cleaning (c) method of back gouging (d) oscillation settings of width, frequency and dwell time (e) number of passes (f) number of electrodes (g) use of nonmetallic retainers (h) electrode spacing (i) vertical progression (j) whether manual or automatic

Table 28-3-4

Characteristic Defects with MIG Welding

DEFECT	CAUSE	DETECTABLE BY
Undercut	insufficient number of passes; excessive current on last pass causing excessive melting of toe	visual inspection or radiography
Burnthrough	excessive current; travel speed too slow	visual inspection or radiography
Porosity	low gas flow; air drafts; excessive gas flow whose turbulence draws in air; failure to use deoxidizers with reactive shielding	liquid penetrant for porosity open to surface; radiography
Incomplete Fusion	incorrect bead sequence; incorrect torch oscillation; current too low; travel speed too high	radiography or ultrasonic
Crack in the Weld Metal	incorrect base metal; incorrect filler wire; preheat too low; concave beads; excessive current; crater cracks	liquid penetrant or magnetic particle for surface; radiography or ultrasonic for subsurface
Underbead Crack	preheat too low; excessive current	radiography or ultrasonic
Spatter	occurs with spray arc and globular transfer; excess spatter can be caused by excess voltage or arc length	visual inspection or radiography

wire and wire feed rate. Travel speed determines bead shape for a given feed rate. These three variables (current, feed rate, travel speed) establish the heating rate at the point of welding. Excessive heating rates give potential for burnthrough on early passes and weld metal and underbead cracking on any pass. Welding root passes by short circuiting transfer or by another process, e.g., TIG, eliminates potential for burnthrough. Proper heating rate and control of preheat and interpass temperatures can eliminate weld metal and underbead cracking.

Some amount of fine porosity normally occurs with MIG welding. The high welding speed makes it virtually impossible to provide perfect shielding. Many applications are not adversely affected by fine porosity. Where fine porosity must be eliminated, MIG welding equipment is placed in a welding chamber which is evacuated and then filled with inert gas, e.g., argon.

SUBMERGED ARC WELDING PROCESS

Description of Process

Submerged arc welding is a process where heat for fusion is produced by an electric arc between a bare wire consumable electrode and the work piece. Shielding is provided by a blanket of granular, fusible flux which completely inundates the arc. Filler material is provided by the consumable electrode.

Equipment

The submerged arc welding process employs a welding head, bare filler wire, granular flux and electrical power supply as illustrated in Figure 28-3-7.

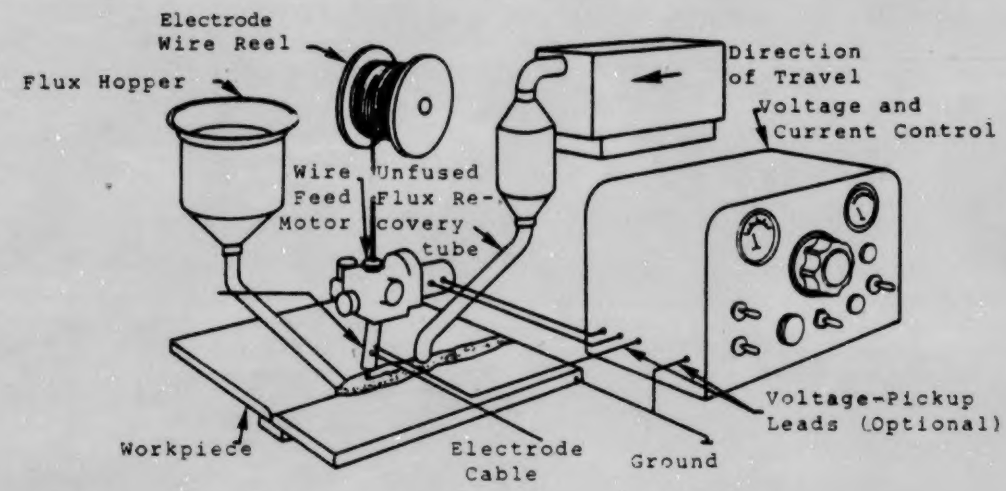
Electrode Wire Reel
Flux Hopper
Direction of Travel
Voltage and Current Control
Wire Feed Motor
Unfused Flux Recovery tube
Voltage-Pickup Leads (Optional)
Workpiece
Electrode Cable
Ground

Figure 28-3-7

Essential Components of a Typical Machine for Automatic Submerged-Arc Welding

Both automatic and semi-automatic submerged arc welding heads are available. An automatic head consists of a motor driven electrode feeder along with necessary electrical connections to introduce the welding current into the electrode.

The wire feeder may be reversing or nonreversing. The automatic head mounting arrangement contains positioning and tracking adjustments to permit locating and holding the arc at the desired location. The positioning equipment may traverse the head along the weld joint or it may hold the head while the weld joint is traversed under it. In either case, precise control of arc location needs to be maintained.

Semi-automatic heads are portable and consist of a small conical flux hopper positioned concentrically about the electrode nozzle tip with a handle attached so that it can be held and manipulated manually. The electrode feeding device is a separate unit which feeds the electrode through flexible tubing to the handle butt. The electrode progresses through the handle to the nozzle assembly which contains electrical connections to introduce current into the electrode.

Straight length or spooled bare wire can be used for filler material. Spooled bare wire is mostly used to take advantage of the high welding speeds attainable with submerged arc welding. Most straight length bare rod applications involve hard surfacing where the low ductility of the hard surfacing filler alloy does not permit spooling. The filler material serves as the electrode and is consumed at a rate equal to the feed rate.

Granular fusible flux provides shielding. It can be manually poured onto the weld joint but normally is automatically fed ahead of the arc from flux hoppers. Sufficient flux is used to completely bury the arc and the resultant weld bead. Submerged arc welding is one of the few welding processes not requiring eye protection other than routing safety glasses for normal eye protection.

Either direct current or alternating current electrical power supplies can be used. They may be constant current types or constant voltage types. As with the MIG process, constant current type power supplies must be used with wire feeders that sense voltage and adjust wire feed rate to maintain proper arc length. Constant voltage types are used with fixed wire feed rates and the power supply adjusts current to maintain proper arc length. At very high welding currents with direct current power supplies, arc blow (wander) becomes a problem due to the associated magnetic fields. Also, if two or more electrodes are employed, no more than one electrode is fed by direct current. Otherwise, the arcs attract or repel each other depending on polarity causing uncontrollable arc wander.

Process Techniques

Prior to arc initiation, flux is preplaced, manually or automatically, so that the entire area surrounding the electrode tip is covered with flux. As welding progresses, flux is added (or has been preplaced) to keep the electrode tip totally submerged. If any sparking is visible, there is not enough flux and more is added.

The arc is initiated by one of several methods. A small ball of steel wool can be placed between the end of the electrode and the work piece to provide short circuiting current path. When current is applied, the steel wool rapidly melts, thereby, creating an arc. This method is used with non-reversible wire feeders. If the wire feeder is reversible, the wire can be prepositioned against the work piece. When current is applied, momentary reversal of wire feed will generate the arc. Scratch starting places the electrode against the work piece, starts travel of the head and wire feed and then applies current. Another method is high frequency current which ionizes the air between the electrode and the work piece to initiate the arc.

Once the arc is initiated, the heat melts the base metal, the electrode, and the granular flux. Since molten flux is much less dense than molten weld metal, it floats on the weld puddle. This molten flux shields the molten weld metal and helps to stabilize the arc. As welding progresses, the trailing edge of the molten flux solidifies forming an adherent slag covering over the solidified weld bead. In this manner, no air can come into contact with the molten weld puddle or the hot weld bead as can be seen in Figure 28-3-8.

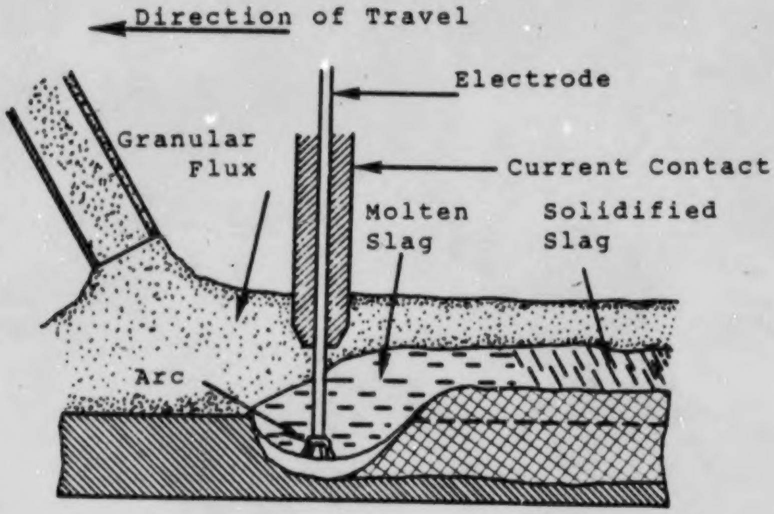

Figure 28-3-8
Diagrammatic Sketch of Submerged Arc Welding Operation on Heavy Plate

As shown in Figure 28-3-8, sufficient flux is used such that excess flux that is still granular remains on top of the slag. This excess flux can be collected by an industrial vacuum machine as shown in Figure 28-3-7. The collected excess flux can be reused provided it is kept clean and dry. After removing the excess flux and after some cooling of the weld bead, the slag must be removed prior to welding the next pass. A manual slag pick will normally remove the slag although some grinding may be needed along the edges of the bead.

In addition to generating slag, fluxes affect the weld metal chemistry to an extent determined by the exact constituents of the flux. Certain fluxes contain predetermined amounts of deoxidizing and alloying ingredients which help achieve the desired weld metal chemistry. These deoxidizing and alloying ingredients are selected based on achieving a desired weld metal chemistry with a known base metal and filler material composition. Other fluxes do not have alloying ingredients but, nonetheless, affect weld metal chemistry at least slightly because no flux is completely non-reactive.

The high current densities employed with submerged arc welding generate considerable heat. The relative amounts of melting of base metal (penetration), filler material (deposition rate), and flux by this heat are determined by several variables selected to give penetration ranging from deep penetration to very shallow penetration.

The type and polarity of current affect penetration and deposition rate. Direct current reversed polarity gives greatest penetration with a corresponding lower deposition rate. Straight polarity gives lower penetration and higher deposition. Alternating current gives penetration and deposition somewhere between direct current reversed polarity and direct current straight polarity.

Current affects penetration and deposition rate. Penetration is proportional to the absolute value of current, i.e., higher current gives deeper penetration and lower current gives shallower penetration. The current density (absolute value divided by cross-sectional area of electrode) directly affects deposition rate. If wire diameter is decreased with a constant current value, deposition rate increases but penetration is unaffected.

Electrode extension or stick out (distance from nozzle tip to electrode tip) affects deposition rate. With all other variables held constant, increasing electrode extension will increase deposition rate and decrease flux consumption and penetration. Since the wire may curl and cause arc wander as electrode extension is increased, wire straighteners are normally integral with the wire feeder mechanism.

Arc voltage has great effect on bead shape and contour but very little effect on penetration. Low voltage results in narrow, rough, bumpy weld beads. High voltage produces broad, flatter beads which may roll over and have incomplete fusion at the edges. Arc voltage also directly affects the amount of flux that melts. Higher voltage will consume more flux.

Travel speed affects bead size and shape. Fast speeds produce narrow beads with penetration restricted to the area close to the electrode position. Slow travel speed produces wider beads with uniform penetration for a considerable distance on either side of the electrode position.

Procedure

Submerged arc welding procedures need to cover the variables listed in Table 28-3-5. Procedures specify specific values for each variable listed.

The rationale for differentation of essential and nonessential variables is the same as that for the TIG welding process.

Flux classification becomes an essential variable because weld metal chemistry is affected, at least slightly, by the flux constituents. Manufacturers of the flux normally hold proprietary the flux composition and flux manufacturing processes but publish data identifying usable flux classifications for various base metal and filler

Table 28-3-5

Procedure Variables for Submerged Arc Welding

FUNDAMENTAL VARIABLES	ESSENTIAL VARIABLES	NONESSENTIAL VARIABLES
Joint Design	None	(a) groove type and design (b) use of backing
Base Metal	(a) material type (b) joint thickness	None
Filler Material	(a) filler material type (b) deposited weld metal chemical composition (c) flux classification	(a) diameter of electrode
Position	None	(a) the welding position to be used
Preheat	(a) a decrease of more than 100°F in specified minimum preheat temperature from that qualified (b) an increase in specified maximum interpass temperature	(a) the minimum preheat temperature (b) whether preheat is to be maintained to post weld heat treatment furnace (c) the maximum interpass temperature
Post Weld Heat Treatment	(a) heat treatment temperature and time	None
Electrical Characteristics	(a) where impact properties are tested, a change in oscillation settings, multipass to single pass, number of electrodes	(a) type of current and polarity (b) current and voltage values
Technique	(a) where impact properties are tested, the type of current and polarity and the amperage and voltage	(a) stringer or weave bead (b) method of initial and interpass cleaning (c) method of back gouging (d) oscillation width, frequency and dwell time (e) number of passes and sequence (f) number of electrodes and electrode spacing (g) use of nonmetallic retainers

material combinations. The data are based on chemically testing the weld metal composition of weld metal test plates welded by submerged arc. Similar test plates are welded by the submerged arc procedure at the job site and chemically tested to confirm correct weld metal composition.

The flat position is best for submerged arc welding due to the large size of molten weld and slag. Horizontal position can be used but coffer dams may be needed to retain the flux. Submerged arc welding is not suitable for overhead and vertical positions.

As with the MIG welding process, multiple electrodes may be used. Also, a "cold" wire (no electrical energy applied) may be fed into the arc generated by the "hot" wire. Either of these techniques increases the deposition rate.

Automatic submerged arc welding equipment normally has oscillation controls to adjust for stringer or weave bead. As with MIG welding, width, frequency and dwell time are adjustable.

Large quantities of slag are produced by submerged arc welding. This slag must be removed after each pass to prevent it being entrapped by subsequent passes.

Welding head tracking is very important. The welder cannot see exactly where the arc is tracking because it is submerged. To ensure proper tracking, automatic submerged arc equipment is carefully prealigned prior to commencing welding. The welder aligns the equipment and traverses the head without starting current or flux. In this manner, the precise path of the electrode can be fixed.

Application

Submerged arc welding is used primarily for welding of ferrous alloys although it is adaptable to other alloys such as nickel-copper. Its capability of adjusting for deep or shallow penetration and its high welding speed makes it beneficial for joint welding and hardsurfacing.

For joints accessible for welding both sides, full penetration can be achieved with a squared butt joint up to about 1 1/8 inches thick. For thicker joints, grooves are needed for full penetration but smaller included angles are possible due to the deep penetration attainable. Most fillet welds on tee joints can be made with one pass. With such ability to reduce weld preparation time and to offer high deposition rates, submerged arc welding is frequently employed where flat or horizontal positioning can be obtained.

For hardsurfacing, submerged arc welding variables are set for shallow penetration and high deposition rate. In this manner, base metal dilution of the weld metal may be from 10% to 20% and the desired surface hardness may be obtained in a single pass.

Characteristic Defects, Their Causes and Detection

Characteristic defects of the submerged arc welding process, their causes and means of detection are listed in Table 28-3-6.

As with the shielded metal arc welding process, interpass cleaning becomes very important to avoid slag inclusions. Large amounts of slag are produced by submerged arc welding which must be removed prior to welding the next pass.

If there is moisture in the granular flux, it decomposes to hydrogen and oxygen in the arc. Hydrogen can cause cracking in alloys subject to attack by hydrogen. Either gas can cause porosity. In order to avoid such problems, granular fluxes are dried by the manufacturers and packaged in vapor proof bags to keep them dry. As an added precaution, fluxes are often baked immediately prior to use.

Table 28-3-6
Characteristic Defects of the Submerged Arc Welding Process

DEFECT	CAUSE	DETECTABLE BY
Undercut	insufficient number of passes; excessive melting of base metal at toe of weld	visual inspection or radiography
Burnthrough	excessive current, insufficient travel speed	visual inspection or radiography
Incomplete Fusion	incorrect tracking of welding head; excessive voltage causing bead rollover; incorrect oscillation settings	radiography or ultrasonics
Crack in Weld Metal	incorrect base metal; incorrect filler material; preheat too low; moisture in flux	surface: liquid penetrant or magnetic particle subsurface: radiography or ultrasonic
Underbead Crack	preheat too low; excessive current; moisture in flux	radiography or ultrasonics
Slag Inclusion	inadequate interpass cleaning	radiography
Porosity	moisture in flux	radiography

Proper setting of electrical variables and adjustment of tracking controls can prevent burnthrough and incomplete fusion. In fact, submerged arc welding has the potential of producing excellent quality welds that are continuously defect free. If the flux is free of moisture and the weld joint is clean, there is essentially no chance or porosity. There is no weld spatter. All the other possible defects can be avoided by proper interpass cleaning and equipment settings.

EXERCISES

Review the information on Submerged Arc Welding Process by completing the following quiz:

Name the function(s) of the apparatus for submerged arc welding:

APPARATUS	FUNCTION
1. granular flux	a.
	b.
	c.
2. spooled bare wire	a.
	b.

Name the primary cause of the weld condition for submerged arc welding.

CONDITION	PRIMARY CAUSE
3. broad, flat bead that rolls over	

CONDITION	PRIMARY CAUSE
4. narrow, bumpy head	
5. burnthrough	
6. slag inclusion	
7. non-overlapping weave beads and incomplete fusion between weave beads	

Classify the statement as true or false for the submerged arc welding process.

8. Extremely high welding speed are obtainable in the flat position.
9. Deposition rate is a function of electrode extension past the welding head nozzle assembly.
10. Loss of argon flow causes porosity.
11. A wide range of penetration can be obtained by adjusting current, feed rate, and electrode extension.
12. This check list summarizes the major points of this module. Put a check by each point as you recall it.

    ____ The tungsten inert gas (TIG) welding process employs a nonconsumable electrode, electrode holder, electrical power supply and a shielding gas supply.

    ____ The material composition of TIG welding electrodes is pure tungsten, tungsten-thorium, or tungsten-zirconium. The latter two provide for higher current density capacity.

    ____ TIG welding may be performed with direct or alternating current. Direct current, straight polarity provides greatest penetration. Direct current, reversed polarity provides least penetration.

____ Pulsed current in the TIG welding process provides for greater penetration with smaller aggregate size of the molten weld puddle. The pulsed current technique has the advantages of increased depth to width ratio of weld beads, elimination of burn-through, and minimal heat affected zone.

____ Argon, helium, or argon-helium mixture may be used for shielding in the TIG welding process. Argon provides for smoothest arc and helium provides for higher arc energy.

____ TIG welding is very versatile and may be used for all alloys and in all positions. It is particularly well suited for welding thin members, root passes, and joints in the overhead and vertical position.

____ The main drawback of TIG welding is its relatively slow welding speed as compared to metal inert gas and submerged arc welding.

____ Porosity in TIG welds is caused by inadequate shielding or arc wander.

____ Incomplete fusion in TIG welds is caused by insufficient current, excessive travel speed, excessive feed rate of filler material, or arc wander.

____ The most likely inclusion in TIG welds is a Tungsten inclusion because slag is not generated by this welding process.

____ Weld metal cracking in TIG welds may be caused by incorrect base metal type, incorrect filler material type, concave weld beads or craters.

____ The metal inert gas (MIG) welding process uses a consumable electrode, gas shielding, welding torch, wire feeder, and power supply.

____ Proper arc length in MIG welding is maintained by either of two methods. Either wire feed rate is automatically adjusted as arc voltage varies or current is automatically adjusted as arc length varies.

____ Spray arc transfer method provides for highest welding speed in MIG welding. In the spray arc method, tiny droplets of molten filler material are sprayed through the arc to the weld joint. In this method, direct current, reversed polarity gives greater penetration than direct current, straight polarity. This effect is caused by the positive gas ions either aiding or resisting the spray of droplets.

____ Below the transition current value, globular arc transfer occurs in MIG welding. Because this method gives less penetration and more arc turbulence and weld spatter, globular arc transfer is rarely used.

____ Short circuiting metal transfer provides for a very stable arc of low energy which is well suited for welding thin members and welding in the overhead and vertical positions. In this method, special current limiting devices in the power supply are necessary and all method transfer occurs during all metal transfer occurs during the short circuit.

____ MIG welding uses argon, helium, argon-oxygen, argon-carbon dioxide or pure carbon dioxide as shielding gas.

____ MIG welding with oxidizing agents in the shielding gas must use fluxes or filler material which contain deoxidizers to avoid arc harshness and considerable spatter. Also alloying ingredients may be used to assist in obtaining desired weld metal chemistry.

____ MIG welding is adaptable to all types of base metals and all welding positions. Spray arc transfer provides for highest welding speeds.

____ Defect prevention in MIG welding is primarily dependent upon obtaining the correct combination of current, filler material feed rate, and travel speed. These three variables establish the heating rate at the point of welding.

____ Fine porosity frequently occurs in MIG welding due to the difficulty of providing perfect shielding. Where such fine porosity is unacceptable, welding is performed in a chamber which has been evacuated and filled with an inert gas such as argon.

____ Submerged arc welding (SAW) uses a welding bead, bare filter wire, granular flux and an electrical power supply.

____ In the SAW process, the granular flux metals in the arc and serves as shielding, arc stabilizer, and deoxidizing and alloying agent.

____ In the SAW process, direct current reversed polarity gives greatest penetration and lowest deposition rate. Direct current straight polarity gives lowest penetration and highest deposition rate. Alternating current gives penetration and deposition rate somewhere between these values.

____ The absolute value of current in the SAW process primarily affects penetration depth while the current density primarily affects deposition rate.

____ Electrode extension in the SAW process primarily affects deposition rate.

____ Arc voltage in the SAW process primarily affects bead shape and contour.

____ Travel speed in the SAW process primarily affects bead size and shape.

____ The SAW process is best suited for ferrous alloys in the flat and horizontal positions. It may employ automatic welding equipemnt in either stringer bead or weave bead modes. It has the capability of adjustment for a wide variety of penetration depths and bead size.

____ The large quantities of slag produced by SAW must be removed prior to welding the next pass.

____ The granular flux used in the SAW process must be maintained dry in order to avoid porosity and cracking.

____ Defects which may occur in the SAW process are undercut, burnthrough, incomplete fusion, weld metal cracking, underbead cracking, slag inclusion, and porosity.

MATERIALS

The following materials will be needed during visits to welding shops:

1. Welder's Goggles or Hoods (hand held face shields are ideal)
2. Temperature Measuring Devices (crayon or contact pyrometer)
3. Lab Coat or Apron or Work Clothes
4. Long Sleeves

PROCEDURES

The following procedures reinforce the information presented in this module. In performing any of these activities, students/trainees should observe the following safety precautions:

- Never look at a welding flame or electric arc without welder's goggles or hoods. (NOTE: sunglasses are inadequate to protect the eyes from the intense light from welding.)
- Wear long sleeves and either work clothes, lab coat, lab apron, or coveralls.
- Avoid stepping on hoses and cables.
- Do not touch or adjust welding equipment unless requested to do so by the instructor or tour guide.
- Do not touch pieces recently welded; they will probably be very hot.

1. Visit a welding shop employing Tungsten Inert Gas welding
   a. On initial arrival at the welding shop, the instructor or a welding shop member will probably guide the students/trainees on a tour of the shop and explain pertinent safety rules to be observed. Subsequently, students/trainees should observe tungsten inert gas welding in progress and complete Data Table 28-3-7 in accordance with this procedure.
   b. Prior to reviewing the corresponding welding procedure, complete steps c, d, e, and f. Use Table 28-3-10 for additional guidance.
   c. Trace the electrical cable from the TIG torch to the power supply. Complete Section A of Data Table 28-3-7, based on observation of power supply settings and instrumentation. The nameplate data should identify if high frequency starting is available.
   d. Return to the welding station and complete Section B of Data Table 28-3-1 based on observation of the welding in progress. In describing weld bead appearance include contour, surface roughness, oxidation and blend with base metal.
   e. Request to see a new electrode that has not been used and an electrode that has been used. Compare their appearance and complete Section C of Data Table 28-3-7. In describing appearance of the electrodes include shape of the arc tip, smoothness of tip and any irregularities.
   f. Trace the shielding gas hose from the torch to the gas bottle(s). Complete Section D of Data Table 28-3-7. If a mixture of gasses is being used, calculate the percentage flow of each.

g. Obtain the procedure that represents the TIG process observed in steps c through f.

h. Compare entries on Data Table 28-3-7 with procedural requirements and list in Section E of Data Table 28-3-7 any differences and potential effects of such differences.

i. Determine for each difference if the potential effect is actually occurring and, if not, offer rationale for why not. Record your determination under the column "actual result" in Section E of Table 28-3-7.

2. Visit a welding shop employing Metal Inert Gas welding

a. On initial arrival at the welding shop, the instructor or welding shop member will probably guide the students/trainees on a tour of the shop and explain pertinent safety rules to be observed. subsequently, each student/trainee should observe metal inert gas welding in progress and complete Data Table 28-3-8 in accordance with this procedure.

b. Obtain the procedure that corresponds with the MIG welding to be subsequently observed and complete Section A of Data Table 28-3-8 from the procedural requirements.

c. Observe MIG welding represented by the procedure and check for compliance with each entry in Section A of Data Table 28-3-8. Use Table 28-3-10 for additional guidance.

d. Observe the MIG arc and determine the type of metal transfer. Record observations in Section C of Data Table 28-3-8.

e. Observe the weld in the welding condition of any pass and complete Section D of Data Table 28-3-8.

f. Review the entries in Section D of Data Table 28-3-8. Entries in the left hand column indicate ideal conditions. Entries in the middle column are less ideal but probably acceptable. Entries in the right hand column are probably unacceptable. For any entries in the right hand column, determine what could be done to eliminate the condition and describe your determination in Section E of Data Table 28-3-8.

3. Visit a welding shop employing Submerged Arc Welding

a. On initial arrival at the welding shop, the instructor or a member of the welding shop will probably guide the students/trainees on a tour of the shop and explain pertinent safety rules to be observed. Subsequently, students/trainees should observe submerged arc welding in progress and complete Data Table 28-3-9 in accordance with this procedure.

b. Obtain the welding procedure that corresponds with the submerged arc welding to be subsequently observed and complete Section A of Data Table 28-3-9 from the procedural requirements.

c. Observe submerged arc welding represented by the procedure and check for compliance with each entry in Section A of Data Table 28-3-9. List any noncompliance in Section B.

d. Observe the removal of slag and visually inspect the weld bead. Complete Section C of Data Table 28-3-9.

e. Review the entries in Section C of Data Table 28-3-9. Entries in the left hand column indicate ideal conditions. Entries in the middle column are less ideal but probably acceptable. Entries in the right hand column are probably unacceptable. For any entries in the right hand column, determine what cound be done to eliminate the condition and describe your determination in Section D of Data Table 28-3-9.

DATA TABLE

Table 28-3-7
Tungsten Inert Gas Welding Data

A. Welding Power Supply Data

Type of Current (AC or DC) ____________________________

Polarity ________________ Amperage ____________________

Voltage ________________ High Frequency (yes/no) _____

B. Welding Station Data

Sketch the weld joint:

Position ________________ Single or Multi-Pass ________

Pass Being Welded _______ Backing _____________________

Filler Material

Size and Type ____

Base Metal Type ____

Preheat Temperature _____ Interpass Temperature _______

Appearance of Weld Bead ________________________________

C. Electrode Data

Type ____________________ Diameter ____________________

Appearance Prior to Welding ____________________________

____

Appearance After Welding _______________________________

____

Would the used electrode cause problems if used again? Why?

D. Shielding Data

	Gas No. 1	Gas No. 2
Type	________	________
Pressure	________	________
Flow	________	________
Percentage Flow	________	________

E. Comparison with Procedure

Differences	Potential Effect	Actual Result

Table 28-3-8

Metal Inert Gas Welding Data

A. Procedural Requirements:

Base Material______________________________________

Welding Process______________________________________

Manual or Machine____________________________________

Position____

Filler Material Type and Size_______________________

Shielding Gas Type________________ Flow_____________

Single or Multiple Pass______________________________

Single or Multiple Arc_______________________________

Current Type (AC or DC)___________ Polarity_________

Oscillation Settings________________________________

Welding Progression_________________________________

Root Treatment______________________________________

Minimum Preheat Temperature________________________

Maximum Interpass Temperature______________________

Post Weld Heat Treatment____________________________

Cleaning Method_____________________________________

Welding Data:

PASS NO.	ELECTRODE SIZE	AMPERES	VOLTS	TRAVEL SPEED	SKETCH JOINT DETAIL

B. Differences between requirements and practice.

Requirements Not Met	Actual Practice
______________________	________________
______________________	________________
______________________	________________

C. Check the type of metal transfer and describe the observations which led to this determination

Type	Basis
___Spray Arc	
___Globular	
___Short Circuiting	

D. As-welded condition (check observed condition).

Bead Contour	___Convex	___Flat	___Concave
Bead Surface	___Almost Smooth	___Rippled	___Bumpy
Toe	___Blended	___Slight Crevice	___Undercut
Oxidation	___None	___Slight Film	___Loose Oxides
Bead Progression	___Straight	___Slightly Crooked	___Misaligned
Spatter	___None	___Little	___Much

E. Determination on As-Welded Condition.

Unacceptable Condition	How Condition Could be Eliminated

Table 28-3-9

Submerged Arc Welding Data

A. Procedure Requirements:

Base Material ______________________________

Welding Process ______________________________

Manual or Machine ______________________________

Position ______________________________

Filler Material Type and Size ____________________

Flux Composition ______________________________

Single or Multiple Pass ______________________

Single or Multiple Arc ______________________

Current Type (AC or DC) _____ Polarity ____________

Oscillation Settings ______________________

Welding Progression ______________________

Root Treatment ______________________________

Minimum Preheat Temperature ____________________

Maximum Interpass Temperature __________________

Post Weld Heat Treatment ______________________

Cleaning Method ______________________________

Welding Data:

PASS NO.	ELECTRODE SIZE	AMPERES	VOLTS	TRAVEL SPEED	SKETCH THE WELD JOINT

B. Differences between requirements and practice.

Requirements Not Met	Actual Practice
____________	____________
____________	____________
____________	____________
____________	____________

C. Slag removal and bead appearance.

Method of Slag Removal ____________

All Slag Removed ____ Yes ____ No

Appearance of Bead.

Contour	____	Convex	____	Flat	____	Concave
Surface	____	Smooth	____	Rippled	____	Bumpy
Toe	____	Blended	____	Undercut	____	Rolled Over
Oxidation	____	None	____	Slight Film	____	Loose Oxides
Progression	____	Straight	____	Slightly Crooked	____	Misaligned
Spatter	____	None	____	Little	____	Much
Stop Crater	____	Filled	____	Concave	____	Cracked

D. Determination on As-Welded Condition.

Unacceptable Condition	How Condition Could be Eliminated
____________	____________
____________	____________
____________	____________
____________	____________

Table 28-3-10

Methods of Checking Welding Requirements

Type of Requirement	Method of Checking
Joint design and fit	Compare sketch or drawing referenced by welding procedure to the physical configuration of the weld joint. Measure required dimensions with mechanical measuring devices
Base metal identification (including backing)	Compare marking on base metal with welding procedure requirements. If unmarked, compare material issue record entries with weld procedure requirements.
Filler material identification	Compare marking on filler material and physical appearance and size of filler material with weld procedure requirements.
Welding position	Compare physical position of weld joint to weld procedure requirement.
Cleanliness	Visually observe for scale, oxides, dirt, oil, etc: compare with welding procedure requirements.
Preheat and interpass temperatures	For preheat, measure base material temperature within one inch of the weld joint with temperature indicating device (e.g. temperature melting crayons, contact pyrometer, thermocouple). For interpass temperature, measure the weld joint temperature immediately prior to commencement of welding.
Gas Pressure	Compare gas pressure meter readings with weld procedure requirements.
Gas Flow	Compare gas flow meter readings with weld procedure requirement.
Nature of oxyacetylene flame	Visually observe flame through welder's goggles or hood; compare with weld procedure requirement.
Welder's technique (forehand, backhand, angle of electrode, progression, interpass cleaning, grinding, back gouging)	Visually observe the welder's practices; compare with welding procedure requirements.
Current type and polarity	Observe switch settings on the electrical power supply for AC-DC and straight-reversal; compare with welding procedure requirements.
Current	Read value on ammeter on power supply or clamp tong ammeter around one cable and read value (NOTE: welding must be in progress to read current or voltage); compare with welding procedure requirements.
Post weld heat treatment	Compare time-temperature chart with welding procedure requirement. Ensure the chart represents the weld joint being checked.

REFERENCE MATERIALS

AWS, Welding Handbook, Section Two, Welding Processes, American Welding Society, Miami, Florida 33125, 1969

ASME, Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, The American Society of Mechanical Engineers, New York, New York 10017, 1978

ASME Boiler and Pressure Vessel Code, Section IX, Welding and Brazing Qualifications, The American Society of Mechanical Engineers, New York, New York 10017, 1978

AWS, D1.1, Structural Welding Code, American Welding Society, Miami, Florida 33125, 1977

AWS, D1.2, Commentary on Structural Welding Code, American Welding Society, Miami, Florida 33125, 1977

AWS, Metals Handbook, Volume 6, Welding and Brazing, American Society for Metals, Metals Park, Ohio, 1971

TEST

Enter the apparatus that performs the function for the tungsten inert gas process:

FUNCTION	APPARATUS
1. Directs current to the electrode and channels shielding gas around electrode.	____________________
2. Encircles electrode at arc end to channel shielding gas flow 360° around electrode.	____________________
3. Nonconsumable electrode that has electron emissivity properties to support an arc.	____________________

List the probable result if the condition is encountered in tungsten inert gas welding.

CONDITION	PROBABLE RESULT
4. Shielding gas flow drops from 15 cubic feet per hour (cfh) to 3 cfh due to pinched gas hose.	____________________ ____________________
5. Procedure has been established for maximum current that will give satisfactory weld with direct current straight polarity. Welder complies with procedure except reversed polarity is inadvertently used.	____________________

6. In welding the root pass of a v-groove joint, the included angle is so small the torch does not gain sufficient access to the root. ______________________________

Circle the number of each application where tungsten inert gas welding represents the best choice of welding processes.

7. Groove joint is 3 inch carbon steel plate in flat position.
8. Groove joint is light gauge sheet metal in vertical position.
9. Root pass in grooved joint of one inch pipe where metalic backing is not permitted.
10. Grooved tee joint in main steel girders for the auxilliary equipment building.

Name the function(s) of the apparatus for metal inert gas welding.

APPARATUS	FUNCTION
11. motorized wire feeder with voltage sensor	a. ____________________ b. ____________________
12. argon	a. ____________________
13. spooled bare wire	a. ____________________ b. ____________________
14. flux in flux cored wire	a. ____________________ b. ____________________
15. constant voltage power supply	a. ____________________ b. ____________________

List the potential effect on weld quality if the condition occurs in metal inert gas welding.

CONDITION	EFFECT
16. spray arc welding where current is lowered below transition current value.	
17. Use of argon and 5% oxygen shielding with filler wire that is non-deoxidizing	
18. Failure to establish preheat prior to spray arc welding of low alloy steel.	

Classify the statement as true or false for metal inert gas welding.

19. Spray arc is best suited for the overhead position. _____

20. Spray arc offers high welding speeds in the flat position. _____

21. Wire speeds and deposition rates are compatible. _____

22. Most shallow penetration occurs with short circuiting metal transfer. _____

23. Deepest penetration occurs with spray arc metal transfer using direct current reversed polarity. _____

Name the function(s) of the apparatus for submerged arc welding:

APPARATUS	FUNCTION
24. granular flux	a.
	b.
	c.
25. spooled bare wire	a.
	b.

Name the primary cause of the weld condition for submerged arc welding.

CONDITION	PRIMARY CAUSE
26. broad, flat bead that rolls over	
27. narrow, bumpy bead	
28. burnthrough	
29. slag inclusion	
30. non-overlapping weave beads and incomplete fusion between weave beads	

Classify the statement as true or false for the submerged arc welding process.

31. Extremely high welding speeds are obtainable in the flat position.
32. Deposition rate is a function of electrode extension past the welding head nozzle assembly.
33. Loss of argon flow causes porosity.
34. A wide range in penetration can be obtained by adjusting current, feed rate, and electrode extension.

NUCLEAR TECHNOLOGY

MODULE 28-4

WELD JOINT VERIFICATION

COURSE 28 WELDING INSPECTION

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
⇨ MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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INTRODUCTION

The type of joint used to join members by welding directly influences the strength of the weld. For this reason, specific types of joints to be used are selected by the designer and shown on design drawings.

For any given type of weld joint, the weld end faces are prepared as necessary to enhance the ability to make defect-free welds. The welding engineer determines the exact weld end preparations that are necessary for a given joint and welding process. Also, the welding engineer determines how joining members should be "fit-up" to permit quality welding. Both weld and preparations and joint fit-up requirements are shown on working drawings and sketches.

The nuclear QA/QC technician confirms, by inspection, that specified requirements are met. This module discusses the nomenclature, symbols, and the purposes of most common joint designs, preparations, and fit-ups. The student/trainee should become familiar with the terms and symbols and understand the basis for the weld joint verification inspections.

MODULE PREREQUISITES

The student must have completed Modules 28-1, 28-2 and 28-3 of this course.

OBJECTIVES

For satisfactory completion of this module, the student/trainee should accomplish the following:

1. Name five basic joint designs, and list their relative ranking by mechanical strength.
2. Name joint design and weld end preparations when given sketches or symbols; sketch the design and draw the symbols when given names of joint designs and weld end preparations.
3. Compare the relative advantages and disadvantages of the various weld end preparations.
4. Interpret welding symbols by stating their meanings.
5. State the reason for cleaning weld joint members.
6. State the purpose of backing rings, consumable inserts, and gas backing.
7. Name three types of fit-up dimensions, and describe their importance to welding.
8. Perform weld joint verification inspections.

TYPES OF WELD JOINTS

General

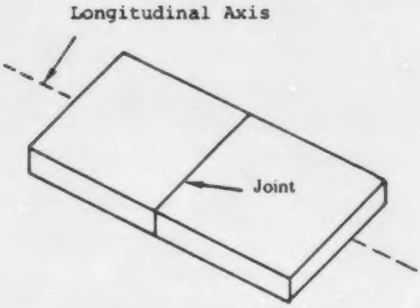
The type of weld joint to be used is normally selected by the designer. One of five basic types of joints is specified: butt, corner, tee, lap, and edge. Design drawings and specifications prepared by the designer specify type and location of weld joints. Also, the designer indicates whether the weld joint is to be welded at the component manufacturer or at the construction site. The manufacturer or the construction contractor prepares working drawings or sketches to identify the precise details of the weld joint.

Types of weld joints are selected to meet the strength requirements of the design. The strength required is influenced by a number of factors, including static and dynamic loading stresses that the weld will see in service. The specific details of weld joint preparation are based on the amount of penetration needed, ability to weld the joint properly, and economy in preparation of the joint.

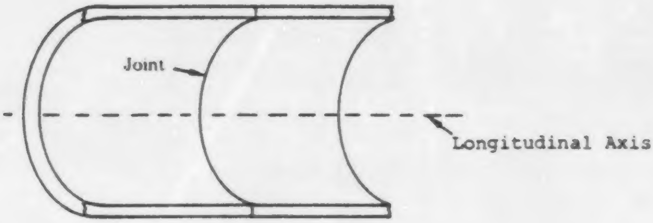
Butt Joints

When joining members are aligned along their longitudinal axes, a butt joint is formed. The degree of alignment (or misalignment) permitted for a butt joint is specified in applicable welding codes. Butt joints can connect plate, tubing, piping, cylindrical parts and structural members.

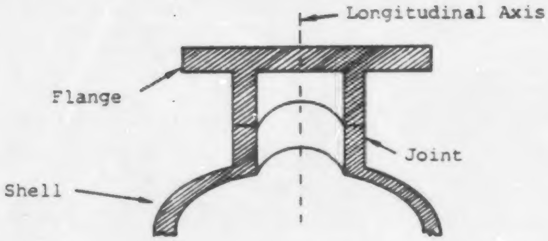
Butt joints are the strongest of all joints. If full penetration welds are made, using butt joints, the strength is equal to that of the base metal, and stresses in service are uniformly distributed throughout the joint. For these reasons, butt joints are commonly used in the manufacture


Longitudinal Axis
Joint

a. Butt Joint in Plate


Joint
Longitudinal Axis

b. Pipe or Tube Butt Joint


Longitudinal Axis
Flange
Joint
Shell

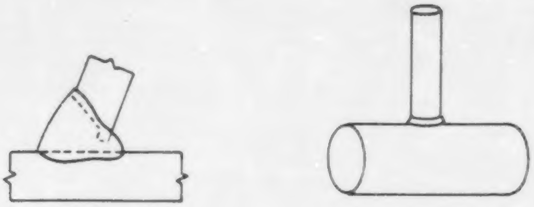
c. Butt Joint in Flange to Shell Connection

Figure 28-4-1
Butt Joints

of pressure retaining components and for joining these components into piping systems for the nuclear power plants. High pressure piping is normally joined with butt joints. Typical butt joints are shown in Figure 28-4-1.

Tee Joints

When joining members form, essentially, a right angle, and are joined at other than their ends, a tee joint is formed. Any restrictions on the angles formed are specified in applicable welding codes. Tee joints can connect plate to plate, pipe to plate, pipe to pipe, and structural steel members to one another. Typical tee joints are illustrated in Figure 28-4-2.



a. Plate to Plate Tee Joint b. Pipe to Pipe Tee Joint

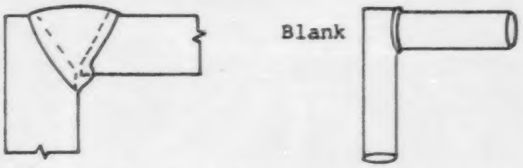
Figure 28-4-2
Tee Joints

Next to the butt joint, tee and corner joints are the strongest. The tee joint's strength is somewhat reduced because of the concentration of stresses at the angles of the joint. A tee joint can be used for full or partial penetration welds. Tee joints permit connecting components at angles for optimizing utilization of space.

Corner Joints

If joining members are joined at their ends and form, essentially, a right angle, a corner joint is formed. Any restrictions on the angles formed are specified in applicable welding codes. Corner joints have the same applications as tee joints.

Corner joint strength is essentially the same as the tee joint's. In most applications, corner and tee joints can be used interchangeably, with respect to strength criteria. Typical corner joints are illustrated in Figure 28-4-3.

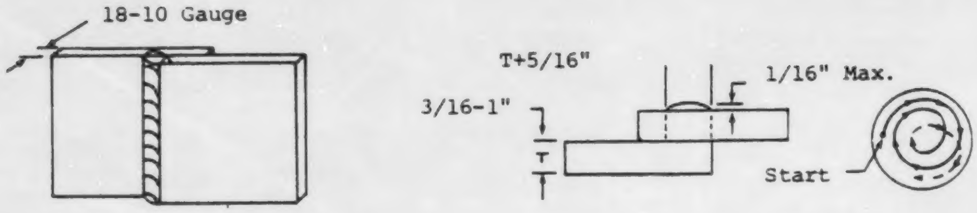


a. Corner Joint in Plate b. Pipe Corner Joint

Figure 28-4-3
Corner Joints

Lap Joints

When joining members overlap one another, a lap joint is formed. Lap joints can be used for joining structural sheet and plate where strength requirements do not demand a butt joint. The lap joint has considerably less strength than the butt, tee, or corner joints. Lap joints are frequently used in the assembly of brackets and braces where space restrictions do not permit access by automatic welding equipment. A typical lap joint is shown in Figure 28-4-4.



a. Fillet Welded Lap Joint   b. Plug Welded Lap Joint

Figure 28-4-4
Lap Joints

Lap joints can be welded by fillet welds or plug or slot welds. In either case, the overlapping members should be clean, and fit tightly against one another. Even so, porosity and slag inclusions are difficult to avoid in the root, because gases and/or slag can be entrapped between the members.

Edge Joints

When the edges of overlapping members are aligned, an edge joint is formed. Edge joints can be used for joining structural sheet material. A typical edge joint is shown in Figure 28-4-5.

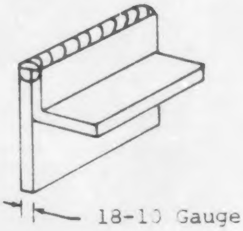


Figure 28-4-5
Edge Joints

Edge joints require tight fit-up, just as lap joints do. Sometimes the edge joint is grooved to obtain greater weld depth. The edge joint is about as strong as the lap joint, and gives considerably less strength than the butt, corner, or tee.

STANDARD SYMBOLS

The American Welding Society publishes a specification (AWS A2.1) which identifies standard welding symbols. These symbols are employed throughout the nuclear industry.

Eight elements comprise the welding symbol: reference line, arrow, basic weld symbols, dimensions, supplementary symbols, finish symbols, tail, and specifications (or references).

Reference Line and Arrow. Construction of the welding symbol begins with the reference line and arrow. On a drawing, the arrow connects the reference line with one side of the weld joint. All entries below this line apply to the "arrow side" of the joint. All entries above the reference line apply to the opposite side of the joint.

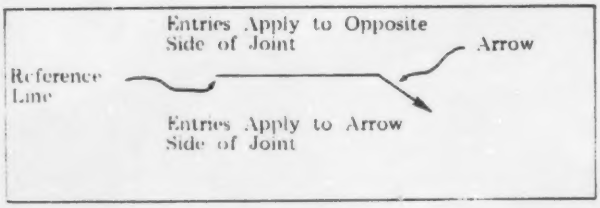

Entries Apply to Opposite Side of Joint
Arrow
Reference Line
Entries Apply to Arrow Side of Joint

Figure 28-4-6
Welding Symbol: Reference Line and Arrow

Basic Weld Symbols. The basic weld symbol denotes the required weld joint preparation. These symbols are illustrated below and are described in detail later in this module.

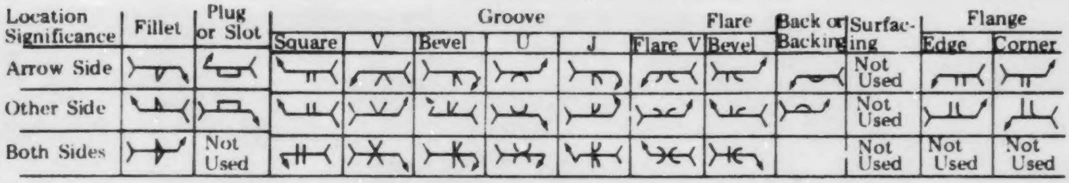
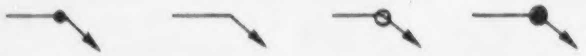

Location Significance
Fillet
Plug or Slot
Groove
Square
V
Bevel
U
J
Flare V
Flare Bevel
Back or Backing
Surfacing
Flange
Edge
Corner
Arrow Side
Other Side
Both Sides
Not Used
Not Used
Not Used
Not Used
Not Used
Not Used
Not Used

Figure 28-4-7

Welding Symbol: Reference Line, Arrow, and Basic Weld Symbol

Supplementary Symbols. Supplementary symbols specify whether the joint will be shop or field welded, whether the joint must be welded "all around", and if weld backing or melt through is required. A field weld is a joint to be welded at the construction site. It is designated by an enlarged dot at the intersection of the reference line and the arrow. Absence of this dot denotes a shop weld. A circle at the intersection of the reference line and the arrow requires that the weld joint be welded for its entire length, or "all around". If only one side is to be welded, that side must be welded for the entire length of the joint. If both sides are to be welded, both sides must be welded for the entire length of the joint. When the weld all around symbol is not used, length and spacing of welds are specified as described later. Weld backing means the deposition of weld beads on the opposite side from the arrow, and it is denoted by an open half-circle above the reference line. Melt through means completely melting the base metal at the root by the first welding pass from the arrow side of the joint. It is specified by a solid half-circle above the reference line.

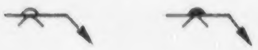


a. Field Weld

b. Shop Weld

c. Shop Weld, Welded all Around

d. Field Weld, Welded all Around



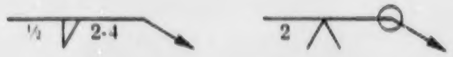
e. Weld Beads to be Deposited on Back Side

f. Weld Through from Groove Side

Figure 28-4-8

Supplementary Symbols and Typical Dimensions

Dimensions, Finish Symbols, Tail, and Specifications. The remaining four elements of the welding symbol are dimensions, finish symbol, tail, and specifications. Frequently, these elements are omitted from the welding symbol because requirements for them are specified elsewhere on the drawing. Of these four elements, dimensions are most often included in the welding symbol. Typically, dimensions are included for welds that are not welded all around and for fillet welds. Dimensions of groove joint preparations are sometimes included.



a. Fillet Weld ¼ by ¼ Inch, Two Inches Long on Four Inch Centers

b. Two Inch V Groove with 1/8 Inch Root Opening and 60° Groove Angle

Figure 28-4-9 Welding Symbol; Typical Dimensions

Composite Welding Symbol - The welding symbol with all eight elements included is structured in accordance with the standard method illustrated in Figure 28-4-10.

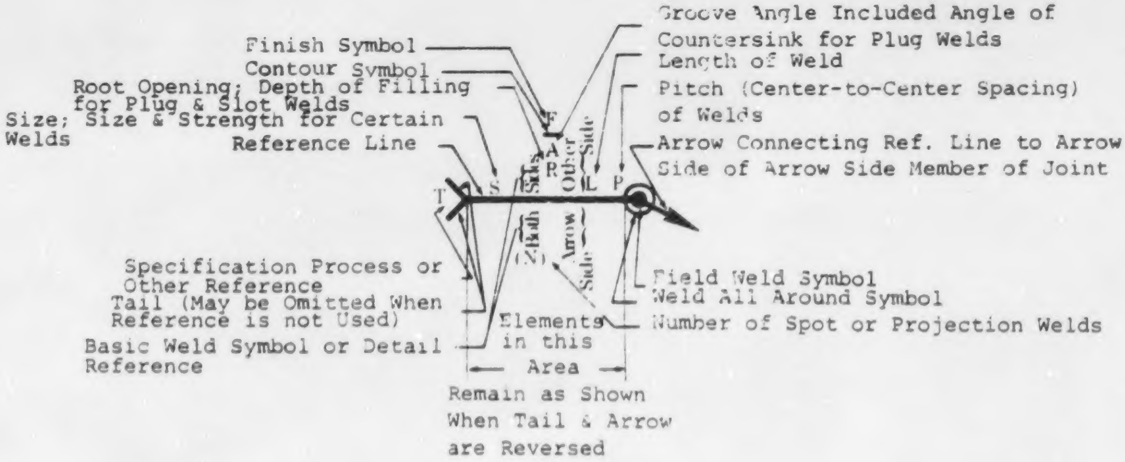

Finish Symbol
Contour Symbol
Root Opening; Depth of Filling for Plug & Slot Welds
Size; Size & Strength for Certain Welds
Reference Line
Specification Process or Other Reference
Tail (May be Omitted When Reference is not Used)
Basic Weld Symbol or Detail Reference
Groove Angle Included Angle of Countersink for Plug Welds
Length of Weld
Pitch (Center-to-Center Spacing) of Welds
Arrow Connecting Ref. Line to Arrow Side of Arrow Side Member of Joint
Field Weld Symbol
Weld All Around Symbol
Number of Spot or Projection Welds
Elements in this Area Remain as Shown When Tail & Arrow are Reversed
F
A
R
S
T
L
P
(N)
Other Side
Both Sides
Arrow Side

Figure 28-4-10

Location of Elements of a Welding Symbol

Referring to Figure 28-4-10, the reference line, arrow, field weld symbol, and weld all around symbol were previously described. The basic weld symbol (see Figure

28-4-7) is placed against the reference line on either the arrow side or opposite side or both, depending on the desired joint preparation. The symbol "S" denotes the position for the dimension of the weld. For fillet welds, this dimension means the size of each leg of the fillet. When the fillet must have unequal legs, the sizes of each are listed with a multiplier sign, e.g., ¼ x ½ means legs of ¼-inch and ½-inch. For groove welds, the "S" dimension refers to the joint thickness. (See Figure 28-4-9a.)

The "R" symbol in Figure 28-4-10 depicts the location of a dimension which specifies a root opening. The "A" symbol represents the location of the value for groove angle of groove welds. Fit-up of the joint ensures compliance with these dimensions. (See Figure 28-4-9b.)

The "L-P" symbol in Figure 28-4-10 represents the location of dimensional values for length and pitch of welds when the joint is not welded all around. This condition occurs most frequently with corner and tee fillet welds and edge and lap welds. (See Figure 28-4-9a.)

The "T" symbol of Figure 28-4-10 can list any one of three items. First, it can list the specification that governs the welding. This typically names the welding procedure specification which gives directions to the welder. Secondly, it can list the welding process to be used. In such cases, letter designations are used. Examples include OAW for oxyacetylene welding, SMAW for shielded metal arc welding, GTAW for gas tungsten arc welding, GMAW for gas metal arc welding (MIG), and SAW for submerged arc welding. Thirdly, the T symbol can identify other reference documents pertinent to welding of the joint. Such reference documents are typically unique to the internal operation of the organization performing the welding.

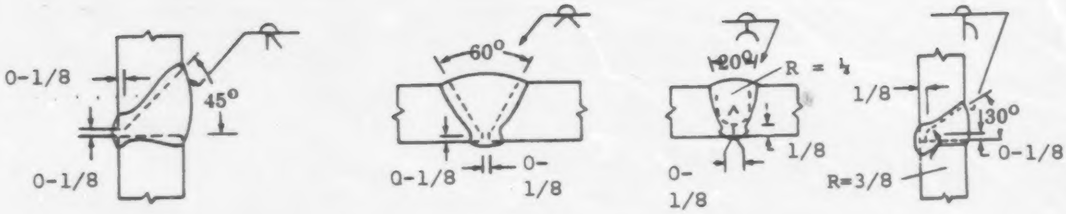
Detailed Weld Joint Preparation

While the type of weld joint dictates the basic strength of the weld, the preparation of the weld joint greatly influences the ability to produce a defect-free weld, and thereby avoid degrading the strength of the joint. The specific preparation to be used is specified by the welding engineer (or other engineer) and is selected to be compatible with the welding process to be used. Thickness of the joint, access to the joint, desired penetration, and joint strength requirements also influence the selection of the joint preparation. Selection of joint preparation must also consider the associated manufacturing costs to avoid unnecessary processing time.

Squared weld end faces offer the most simple joint preparation. If the joint members are routinely fabricated with squared ends by the material supplier, no further preparation is required (other than cleaning). For other members, squared weld end faces can be made by flame or arc cutting, sawing, stamping, milling, or machining. Flame or arc cutting is normally the least expensive method, but usually must be followed by grinding to smooth the surface finish. Milling and machining are rarely used due to their cost.

The squared joint is most suitable for partial penetration welds, and for thin members where full penetration is achievable with a squared joint. It is frequently employed for partial penetration fillet welds and for submerged arc welding of members whose thickness is one inch or less.

Grooved weld preparations permit greater access to the root, and are employed for most joints that require full penetration welds. Figure 28-4-11 illustrates the four types of grooves most commonly used.



a. Bevel b. V c. U d. J

Figure 28-4-11
Single Groove Weld Joints

Each of the grooved weld joints share three features: root land, root opening, and groove angle. The root land thickness provides base metal that supports the molten weld puddle on the root pass. If a feather edge is used, burnthrough is much more likely to occur. The root gap is based on preventing distortion. The combined effects of penetration, deposition rate, and root gap determine the extent of base metal distortion during root pass welding. The groove angle affects the accessibility of the welding apparatus to the joint.

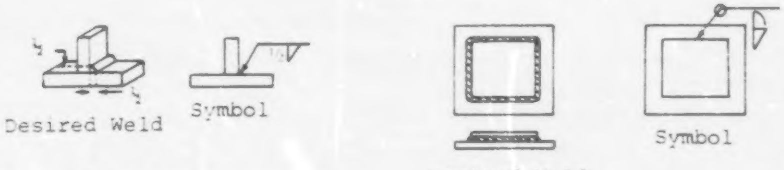
The bevel groove joint requires least manufacturing steps to prepare, and it gives good access to the root. But the squared face of one side of the joint can present difficult welding conditions, dependent on position of the joint and freedom to adjust torch angle. Such difficulties raise the probability of incomplete fusion along the squared face.

While requiring essentially twice the effort to prepare as the bevel joint, the V groove eliminates the squared face. Regardless of welding position, it offers little hinderance to making a sound weld. However, both the bevel groove and the V groove require considerable addition of weld filler material. This disadvantage can be overcome by using U or J groove weld joints.

Comparison of the groove angles in Figure 28-4-11 reveals that U grooves and J grooves require less filler material than bevel or V grooves. In addition, more accessibility is afforded at the root due to the shape of U and J grooves. While more difficult to prepare than the other grooves, U or J grooves are used for thicker joints to provide ample root accessibility and least addition of filler material.

The U and J grooves are prepared by machining and are relatively expensive. Overall cost savings are realized in members thicker than 1½ inches, due to less passes and filler material needed to fill the joint. Like the bevel groove, the J groove has one squared face. If the squared face represents difficult welding conditions, a U groove is used.

Fillet welded joints provide an economical weld when full penetration is not required. Also, fillet welds can be used to reinforce groove welds. These applications are illustrated in Figure 28-4-12.



a. Single Fillet

b. Single J Groove, Fillet Reinforced

Figure 28-4-12
Fillet Welds

Double Welded Joints

Joints that are prepared for welding on both sides are termed double welded joints. Such joints can be employed for fillet welds and for any of the groove welds. Double welded joints are typically used when material thickness exceeds 3/4 inch and both sides of the joint are accessible for welding. Weld symbols for double welded joints are given by Figure 28-4-7.

Double welded joints offer easier distortion control. Opposite sides of the joint can be alternately welded such that shrinkage stresses tend to work in opposite directions.

WELD JOINT FIT-UP

Weld joint fit-up refers to all the necessary steps to bring weld joint members into proper position for welding. It also includes cleaning of weld joint members to remove surface materials that could be detrimental to weld quality. Therefore, fit-up includes cleanliness, alignment, and backing or consumable inserts.

Cleanliness

The weld end preparations of joining members will have residue from the cutting or machining process employed to make the preparation. Shop dirt may settle on the members. Also, the members may oxidize at least slightly in normal atmospheric conditions. For these reasons, a cleaning step always immediately precedes bringing weld joint members into alignment for welding. This cleaning serves to remove surface materials that could be detrimental to weld quality.

The cleaning method selected is based on the conditions of the weld joint members and their base material types.

It may be as simple as a cloth wipe with a detergent cleaner followed by a rinse cloth wipe. It may be a complex pickling process. For most applications, cleaning methods listed in Table 28-4-1 will suffice. Course 30, Mechanical Inspection, discusses specific cleaning processes and their application.

Table 28-4-1
Typical Cleaning Methods for Weld Joints

Undesired Surface Condition	Cleaning Method
Oxides, Scale	light grinding or wire brush followed by hot alkaline wash and water rinse
Oil Grease	detergent wash, water rinse
Paint, Crayon, Ink	paint remover followed by detergent or solvent wash and water rinse
Grit, Dirt, Lint	detergent wash, water rinse

Alignment

Weld joint alignment has two purposes: to make a fit-up suitable for quality welding and to minimize distortion. As discussed in Module 28-1, physical restraints (e.g., clamps, fixtures, braces), holds the weld joint members to minimize distortion from welding stresses. These physical restraints are adjusted in concert with supports (e.g., tables, positioners, stands) to not only hold weld joint members but also to properly align them. Alignment typically involves compliance with specified values for root gap, offset and geometrical form such as runout, perpendicularity, angularity, straightness or parallelism. These types of features are illustrated in Figure 28-4-13.

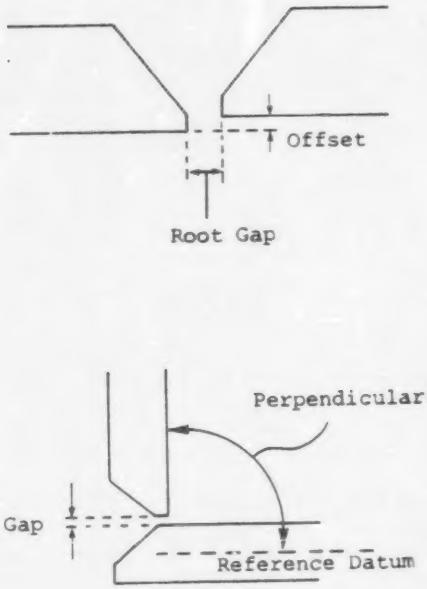
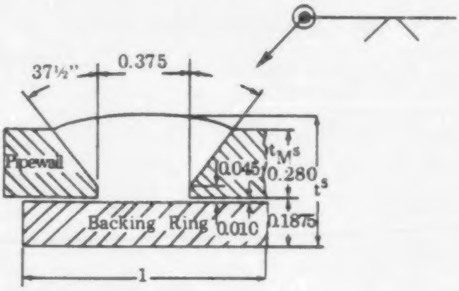


Figure 28-4-13
Alignment Features

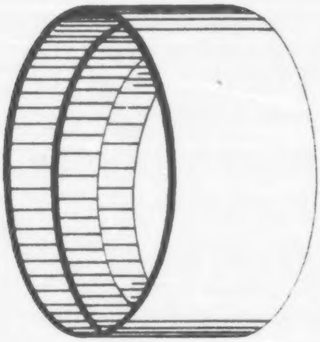
Backing Strips and Rings

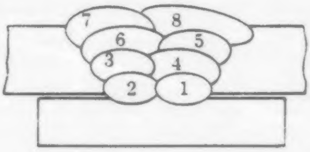
Backing strips or rings have the purpose of supporting the root weld layer for joints that can be welded from only one side. In those applications where high quality root welding is required but welding access to the reverse side is restricted, a backing strip (for plate) or backing ring (for cylinder and pipe) is fit-up to the joint. Such backing is normally of the same material as the base material of the joining members. A typical fit-up with a backing ring in a single V butt joint in pipe is shown in Figure 28-4-14.

Figure 28-4-14 gives a fit-up dimension of .010 inch for the annular gap between the outer diameter of the backing ring and the inner diameter of the pipe. This annular gap should be small in order to promote good penetration in both the joining members and the backing ring by the root welding passes (passes 1 and 2 in detail b).


37½"
0.375
Pipewall
t_M^s
0.045
0.280
t^s
Backing Ring
0.010
0.1875
1

a. Joint Design and Fit Up





b. Bead Placement and Sequence

c. As Welded Condition

Figure 28-4-14

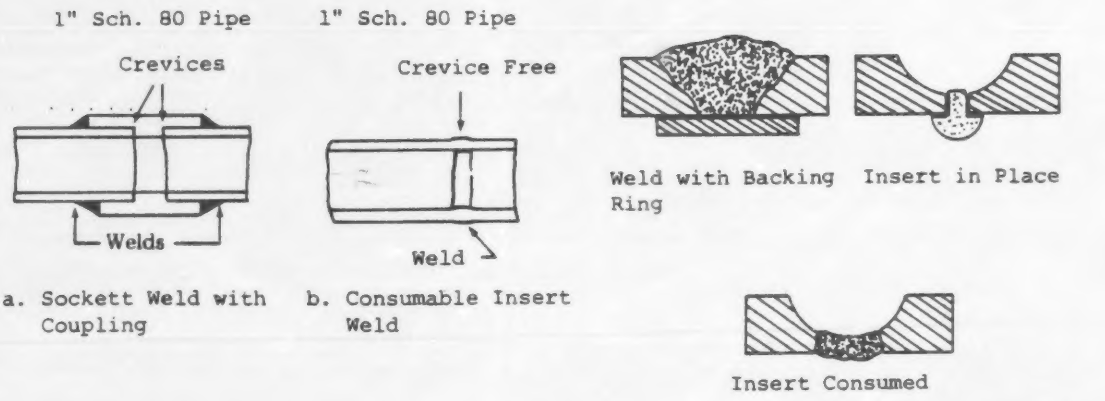
Single V Butt Joint in Pipe with Backing Ring

It can be observed from Figure 28-4-14 that an open space (crevice) exists in the completed weld between the pipe and outer portions of the backing ring. This space can permit accumulation of sediments in service that may promote accelerated corrosion or unacceptable "hot spots" if the deposit is radioactive. In addition, the presence of the backing ring does provide some restriction to fluid flow. Each case, therefore, must be evaluated and the correct fit-up and welding procedure must be followed to adhere to code requirements. Therefore, some applications require the removal of the backing ring after welding.

Consumable Inserts

Consumable inserts provide a method of obtaining crevice-free root welds for weld joints that cannot be welded from both sides. Where a backing ring is unacceptable because it cannot be removed as required to avoid crevices, a consumable insert provides a solution. Generally, backing rings are not used or allowed to remain in the stainless steel piping systems which carry radioactive liquids at a nuclear plant. Consumable inserts are used to avoid the development of "hot spots" from accumulated radioactive corrosion or erosion products flowing through the system.

Also, if crevices that are characteristic of socket welds are unacceptable, the consumable insert can be used. These applications are shown in Figure 28-4-15.


1" Sch. 80 Pipe
Crevices
Welds
1" Sch. 80 Pipe
Crevice Free
Weld
Weld with Backing Ring
Insert in Place
Insert Consumed

a. Sockett Weld with Coupling

b. Consumable Insert Weld

c. Comparison of Backing Ring and Consumable Insert Welds

Figure 28-4-15
Application of Consumable Inserts

Gas Backing and Purge

For joints welded from only one side, the reverse side oxidizes if it is in a normal atmosphere. In many applications, this does not pose a problem. However, for piping in high pressure water systems such as the primary coolant system, oxidation of the reverse side can cause accelerated corrosion and lead to premature failure of the weld joint. For joints where reverse side oxidation is of concern but the reverse side is not accessible, shielding is applied to prevent the oxidation.

Reverse side shielding is accomplished with the same types of inert gases used in welding processes. To differentiate from that shielding, the term gas backing or purge is used for inert gases applied to the reverse side. Figure 28-4-16 illustrates a gas backing and purge set up.

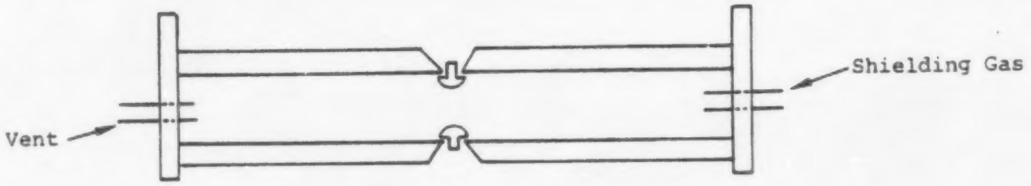


Figure 28-4-16
Gas Backing and Purge

When gas backing is required, the welding procedure specifies the gas type, amount of purge, and gas flow (or pressure). Prior to commencement of welding, the backing gas is directed through the pipe (or other component) for a time calculated to more than totally displace the atmosphere (normally at least twice as long). After displacement of the atmosphere, the inlet and outlet may be sealed (such as by closing valves in hose lines) and the flow stopped, or the gas flow may be continued for the duration of the welding.

VERIFICATION INSPECTION

Weld joint verification inspection confirms that specified requirements are met prior to commencement of welding. This verification inspection is primarily a visual inspection, although some dimensional inspection is necessary. The QA/QC technician normally performs this inspection. Acceptance criteria are either specified within the welding procedure or are referenced by it.

Weld joint verification inspection occurs at the point in time that the welder is making the fit-up immediately

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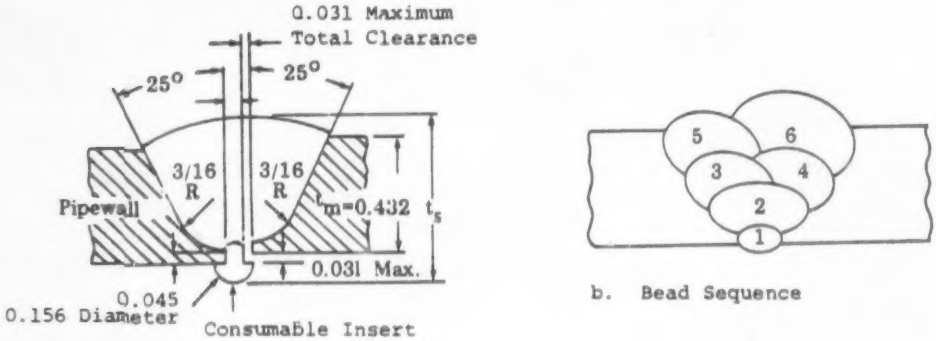
prior to commencement of welding. At that point, the QA/QC technician confirms that welding may commence. This confirmation is based on the results of inspecting material identities, cleanliness, joint type, weld end preparation, fit-up, welding data, qualifications, and process controls. Module 28-6 discusses each of these in detail. Therefore, this module is limited to those inspections pertaining to joint type, weld end preparation, and fit-up.

Welding procedures contain or reference sketches or drawings that specify joint type, weld end preparations, and fit-up. Details (a) and (b) of Figure 28-4-17 give typical sketches.

Visual inspection confirms joint type. As shown in detail (a) of Figure 28-4-17, the specified joint is of the butt type.

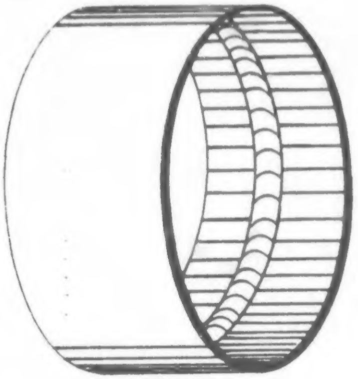
Weld end preparations are often dimensionally inspected at the time they are machined, and need only be visually inspected at fit-up. If dimensional inspection has previously been performed, the fit-up inspection visually observes for no damage to the weld end preparation. If dimensional inspection has not been performed previously, it is performed at fit-up inspection. For the joint shown in Figure 28-4-17, three dimensions would be inspected. These are the .045 inch land, the 3/16 inch J prep radius, and the 25° included angle.

Fit-up dimensions are inspected at the time of weld joint verification inspection. For the joint shown in Figure 28-4-17, two fit-up dimensions are specified. These are the .031-inch maximum gap between the insert crown and pipe inner diameter, and the .031-inch maximum gap between the insert leg and the weld prep land. This latter gap is specified as a total clearance gap. This means that the gap can exist on one side of the insert leg or on both sides of the insert leg provided that the sum of the two gaps does not exceed .031-inch. While geometrical form is not specified in Figure 28-4-17, the two fit-up dimensions could not be met if much misalignment were present.


0.031 Maximum
Total Clearance
25°
25°
3/16
R
3/16
R
Pipewall
t_m=0.432
t_s
0.031 Max.
0.045
0.156 Diameter
Consumable Insert
5
6
3
4
2
1

a. Joint Design and Fit Up

b. Bead Sequence



c. As Welded Condition

Figure 28-4-17

Single U Groove Butt Joint in Pipe with Consumable Insert

SUMMARY

In summary, then, the following key points should be recalled:

a. Weld joint members are cleaned immediately prior to fit-up to remove surface materials that could cause porosity, inclusions, or incomplete fusion in the weld.

b. Weld joint members are aligned and held in position for welding by physical restraints such as clamps, fixtures and braces.

c. Fit-up dimensions typically include root gap, offset, and geometrical form.

d. Backing strips or rings support the root pass weld puddle.

e. Where crevices or excessive pressure drop in the pipe are not permitted, the backing ring must be removed.

f. A consumable insert becomes the root weld when it is consumed.

g. Consumable inserts permit making crevice-free welds when the reverse side is inaccessible.

h. The welding procedure and associated drawings and sketches specify special fixturing, fit-up dimensions, use of backing strip or ring or consumable insert, use of gas backing, and cleanliness requirements.

EXERCISES

Perform the following exercises as a means of reinforcing your knowledge of the material covered in this module.

1. Match the joint design with its description by placing the correct letter from the right-hand column with each definition in the left-hand column:

Definition

___ a. Joining members are placed side by side such that the end edge of one member forms a joint with the face of the other member.

___ b. Joining members are aligned along their longitudinal axes.

___ c. Joining members are placed side by side with their end edges in alignment.

___ d. Joining members are placed at right angles at their ends.

___ e. The end of one joining member is placed against the face of the other joining member to form a right angle.

Joint Design

(1) butt

(2) tee

(3) corner

(4) lap

(5) edge

2. List five types of weld joints in order of their relative strength, with the strongest joint listed first.

a. ____________

b. ____________

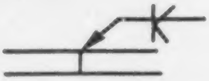
c. ____________

d. ____________

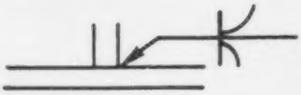
e. ____________

3. Name the weld joint type and preparation represented by the following sketches and symbols:

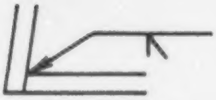
a.



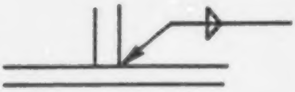
b.



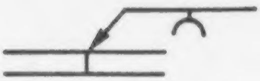
c.



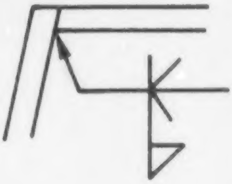
d.



e.

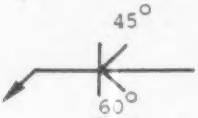


f.

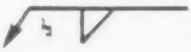


4. For the following welding symbols, state the meaning of the numerical values.

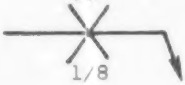
a.



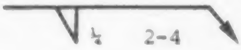
b.



c.

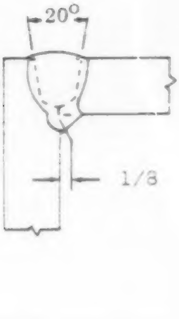


d.

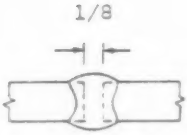


5. Sketch the welding symbol for the following weld joints.

a.



b.



6. Perform the inspection of welding qualification mock-ups as outlined in the PROCEDURES section of this module and collect the data specified.

7. Visit a welding shop and collect the data specified in the PROCEDURES section of this module.

MATERIALS

To avoid excessive trips to welding shops, the following materials are suitable for classroom training aids:

- plastic models of weld joints
- welding qualification mock-ups
- welding qualification test specimens

PROCEDURES

Laboratory/classroom exercises or field trips are recommended to permit students/trainees to inspect weld joints. Depending on local circumstances, weld joints may be accessible by any of the following methods:

- Welding shop within the institution
- Welding shop at a nearby vocational school

- Commercial welding shop
- Welding qualification mock-ups from nearby industries
- Plastic models of welding qualification mock-ups
- Nearby industry or nuclear power plant employing welding

1. Inspection of Welding Qualification Mock-Ups
    a. Students/trainees visually inspect each mock-up and complete applicable portions of Data Table 28-4-1.
    b. For each fit-up dimension contained by the mock-up, student/trainees state the purpose of the dimension on Data Table 28-4-1.
    c. For mock-ups containing backing strips/rings or consumable inserts, students/trainees describe the observable features of the backing insert on Data Table 28-4-1.

2. Visit to a Welding Shop
    a. Observe safety rules applicable to the welding shop.
    b. Each student/trainee select one welding operation and complete Data Table 28-4-1 by visually observing the weld joint.

DATA TABLE

Data Table 28-4-1

1. Sketch the weld joint configuration and fit-up based on visual inspection of a welding qualification mock-up

or a welding operation. Show joining members, weld end preparations, backing or inserts. Label key features.

SKETCH

2. Circle the proper entry below based on visual inspection of the mock-up or weld joint.

Type	Preparation	
Butt	Single	Squared
Tee	Double	Bevel
Corner		V
Edge		U
Lap		J
		Fillet
		Other (explain)

3. Backing Strip or Ring

Used Not Used

Description of condition, if used:

Uniformity of gap____________________
Degree of weld penetration____________________
Cleanliness of gap____________________

4. Consumable Insert

Used Not Used

Description of condition, if used:

Uniformity of gap____________________
Uniformity of insert melting____________________
Convexity____________________
Concavity____________________

5. Gas Backing or Purge

Used Not Used

Data, if used:

Gas type____________________
Purge time____________________
Gas flow____________________

6. Fit-up dimensions (check applicable ones and enter their purpose):

Type of Dimension	Purpose
Root gap	
Backing strip or ring spacing	
Consumable insert spacing	
Geometrical Form (Specify_________)	
Offset	

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Section III, American Society of Mechanical Engineers, New York, N.Y. 10017

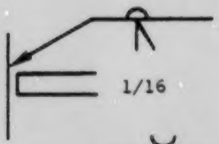
AWS, D1.1, Structural Welding Code, American Welding Society, 2501 N.W. 7th Street, Miami, Florida 33125.

ASM, Metals Handbook, Volume 6, Welding and Brazing, American Society for Metals, Metals Park, Ohio 44073.

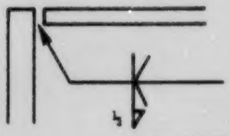
TEST

For each of the following sketches, name the weld joint type and preparation and state the meaning of the numerical values. Use the table following sketches to record answers.

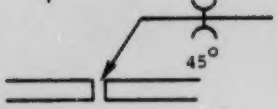
1.



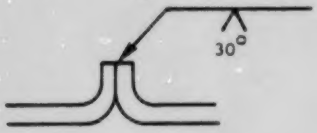
2.



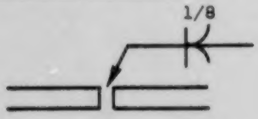
3.



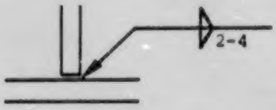
4.



5.

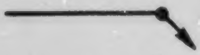


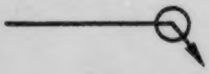
6.



Q	Type	Preparation	Meaning of Numerical Values
1			
2			
3			
4			
5			
6			

For each of the following supplementary weld symbols, state symbol's meaning.

7. 

8. 

9. List five types of weld joints in order of their relative strength (from highest to lowest).

10. State an advantage of single J groove compared to single bevel groove.

11. State an advantage of the V groove compared to squared weld joint.

12. State disadvantage of single J groove compared to single U groove.

13. State an advantage of double V groove compared to the single V groove.

14. State the reason for cleaning weld joint members prior to welding.

15. State the purpose of a backing ring.

16. Describe why a backing ring must be removed after welding in many applications.

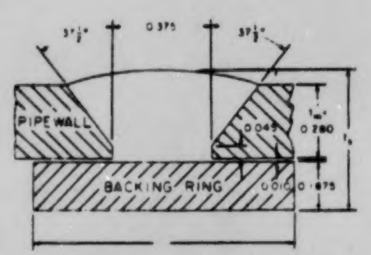
17. State the purpose of a consumable insert.

18. Name three dimensional features that are normally specified for fit-up of weld joint members.

19. Describe how backing gas is beneficial to certain welding applications.

20. When backing gas is used, how is it known that the normal atmosphere has been completely displaced by the backing gas.

21. For the weld joint sketched below, list those dimensions pertaining to weld end preparation and those pertaining to weld joint fit-up.



DO NOT FILM

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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NUCLEAR TECHNOLOGY

MODULE 28-5

QUALIFICATIONS

COURSE 28 WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

.202-A

INTRODUCTION

The welding engineer is responsible for the preparation and qualification of welding procedures. Either the welding engineer or the welding department manager is responsible for qualifying welders. The QA/QC Technician is responsible for monitoring these qualifications to assure compliance with governing welding codes. In addition, the QA/QC Technician monitors production welding to determine that qualified procedures and welders are used.

Prior to any welding taking place, the welding procedure and the welder are required to be qualified by governing welding codes. While welds are nondestructively examined for welding defects, the total quality of the weld cannot be determined solely by nondestructive examination. Destructive tests, such as tensile and bend tests, are required to determine the mechanical properties of the weld (strength, ductility, toughness). Because production welds cannot be destructively tested, their mechanical properties can be ascertained by qualifying the welding procedure and the welder and by ensuring compliance with the qualified procedure during production welding.

This module describes qualification requirements for welding procedures and welders and the role of the Nuclear QA/QC Technician. The module includes discussion of applicable codes and methods of qualification stipulated therein. It describes administrative controls for training from a welded joint to the procedure and welder qualification records. It describes the destructive and nondestructive testing which determines acceptability of qualification. It describes requirements for requalification of welding procedures and welders.

MODULE PREREQUISITES

Modules 28-1 through 28-4 shall be completed before beginning this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Describe the general responsibilities of the QA/QC Technician with respect to welding qualifications.
2. Match any of the three welding codes to their applications.
3. Describe the general method for qualifying welding procedures and welders.
4. State the purposes of the following documents:
   a. welding procedure specification
   b. procedure qualification record
   c. welder qualification record
5. Describe the administrative controls that permit tracing from a welded joint to the welding procedure, and the welder and the qualification records of each.
6. State the rationale for given requirements pertaining to the welding of a qualification test piece.
7. Demonstrate the ability to determine qualification requirements for a given welding procedure or welder and applicable welding code.
8. Name three types of mechanical tests used in welding procedure qualifications and state the purpose for each test.

9. Describe the condition to be met for a bend test specimen to be categorized as side bend, face bend and root bend.
10. Determine for stated changes to welding procedures or welder's assignments if requalification is required, given a welding code or set of essential variables governing qualification requirements.

CODES AND STANDARDS

General

Qualification criteria are set forth by the code or standard that governs the welding of components, systems, or structures. For nuclear power plants, one of three welding codes apply to practically all welding. These codes are: (1) ASME Boiler and Pressure Vessel Code, (2) AWS Structural Welding Code, and (3) AWS Reinforcing Steel Welding Code.

ASME Boiler and Pressure Vessel Code

The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code is applied to welding of nuclear power plant items classified as "safety related". The definition of "safety related" is:

> Those plant features necessary to assure the integrity of the primary coolant pressure boundary, the capability to shut down the reactor and maintain it in a safe shut down condition, or the capability to prevent or mitigate the consequences of accidents which could result in off site exposures comparable to the guideline exposure of Title 10, Code of Federal Regulations, Part 100, "Reactor Site Criteria".

From this definition, one can generalize that the ASME Boiler and Pressure Vessel Code applies to reactor systems, reactor and containment safety systems, and safety related appurtenances such as supports, hangers, brackets and foundations. Section IX of the ASME Boiler and Pressure Vessel Code specifies the qualification requirements pertaining to welding procedures and welders under this code. This code requires successful completion of specific tests of welded specimens as the prerequisite for qualification of both procedures and welders.

AWS Structural Welding Code

The American Welding Society (AWS) Structural Welding Code D1.1 describes welding requirements that could be applied to any type of welded structure. Designers of nuclear power plants often invoke this code for welding of structures that are not classified as safety related. Section 5 of this code stipulates the qualification requirements. It permits declaring a welding procedure as being prequalified if the procedure meets the requirements and limitations of this code. If not or if requested by the purchaser, the welding procedure qualification is based on satisfactory completion of specified tests on welded specimens. For welders, this code requires satisfactory completion of specified tests on welded specimens for certification of qualification.

AWS Reinforcing Steel Welding Code

The AWS Reinforcing Steel Welding Code, D12.1 describes the welding requirments applicable to the welding of reinforcements in concrete structures. This code is referenced by concrete standards issued by the American Concrete Institute as an acceptable code for welding of reinforcements in concrete structures. Section 6 of this code specifies qualification requirements for both welding procedures and welders. In both cases, qualification is based on the satisfactory completion of specific tests on weld test specimens.

QUALIFICATION TECHNIQUES

Overview

Welding procedures are qualified in order to demonstrate that the procedure will produce a weld that meets the requirements specified by the designer. Such requirements typically pertain to strength aspects but sometimes include the weld's resistance to corrosion. Welders are qualified in order to demonstrate that the individual, when using a qualifed procedure, can make a sound weld.

The welding engineer is normally responsible for preparation of welding procedures and the instructions for qualifying both procedures and the welders. The QA/QC Technician monitors the qualifications to assure compliance with the applicable welding codes.

The qualification method is the welding of a qualification test piece (or coupon) in accordance with a welding procedure specification and subjecting the welded piece to tests that determine the quality of the weld. The governing welding code stipulates requirements pertaining to the test piece (such as material, thickness, and position) and requirements pertaining to the tests (such as type, number, location of test specimen, testing techniques, and acceptance criteria). This module generally describes the requirements of the ASME Boiler and Pressure Vessel Code since it is the more stringent of the welding codes and it encompasses the requirements of the other codes.

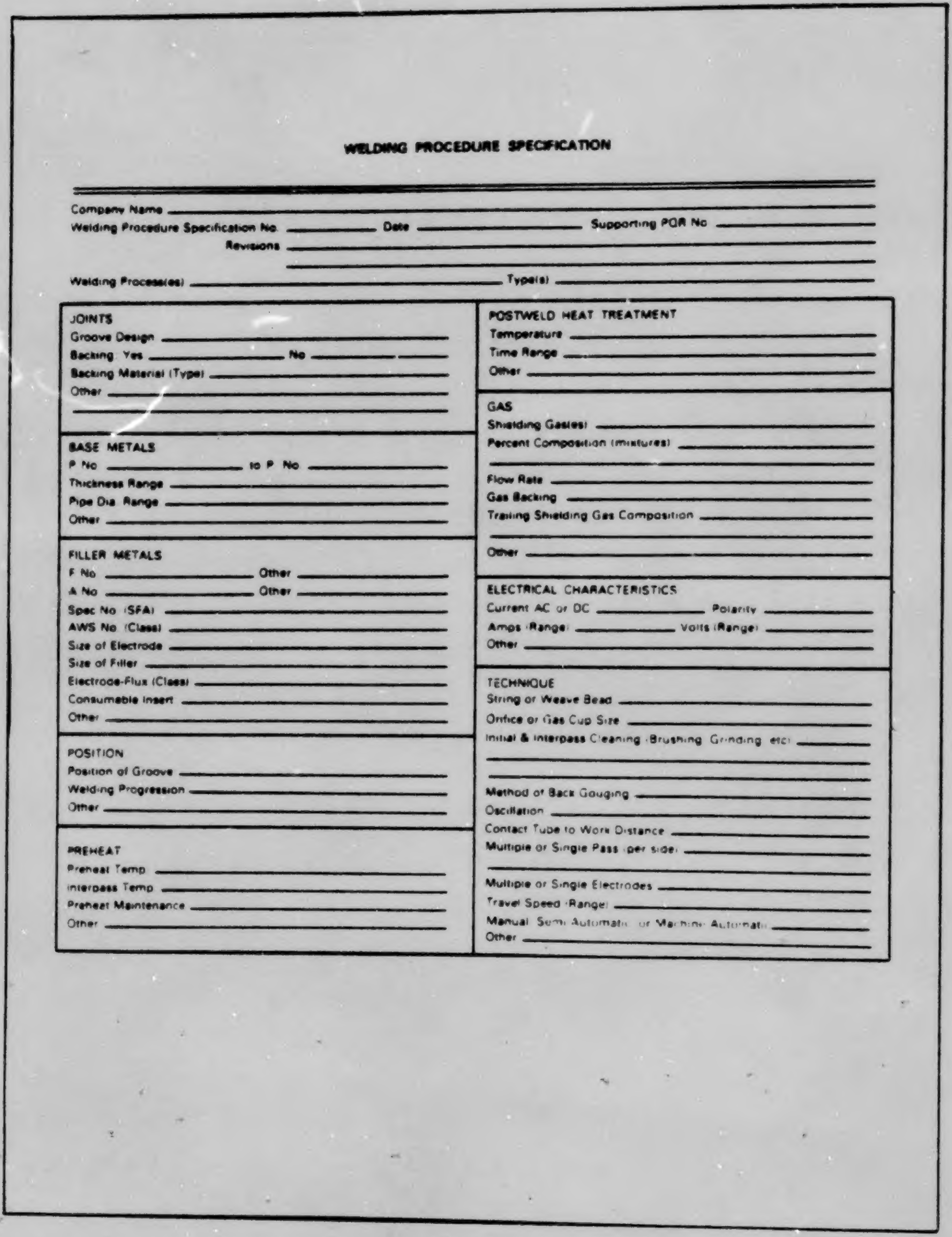
Welding Procedure Specification

The welding procedure specification provides the welder with the necessary direction to weld in accordance with the welding code. It is available to the welder at the welding station. It may or may not be supplemented by a more detailed welding procedure dependent on local circumstances. Such supplementary welding procedures must be consistent with the welding procedure specification.

The welding procedure specification details the instructions and parameters to be followed by the welder for all essential and nonessential variables applicable to the welding process. Essential variables are those which require requalification when changed beyond limits. Nonessential variables are those that can be changed without requalification.

Each welding procedure specification must be supported by qualification tests. A typical format for welding procedure specification is given in Figure 28-5-1.

Space for two key identifying numbers is provided at the top of the form illustrated in Figure 28-5-1. In the upper left hand corner, the welding procedure specification number is recorded. In the upper right hand corner, the serial number of the supporting procedure qualification record is recorded. These two numbers are assigned by the organization responsible for welding and each is unique in that it is never used more than once. Therefore, reference to the first number permits retrieval of the welding procedure specification which in turn references the record that contains the correspondence qualification test results. All other records and procedures pertaining to welding operations reference the welding procedure specification number. For example, an installation record would identify the number of the welding procedure specification that



WELDING PROCEDURE SPECIFICATION

Company Name ________
Welding Procedure Specification No. ________ Date ________ Supporting PQR No ________
Revisions ________
____
Welding Process(es) ________ Type(s) ________

JOINTS
Groove Design ________
Backing: Yes ________ No ________
Backing Material (Type) ________
Other ________
____

BASE METALS
P No ________ to P No ________
Thickness Range ________
Pipe Dia. Range ________
Other ________

FILLER METALS
F No ________ Other ________
A No ________ Other ________
Spec No. (SFA) ________
AWS No. (Class) ________
Size of Electrode ________
Size of Filler ________
Electrode-Flux (Class) ________
Consumable Insert ________
Other ________

POSITION
Position of Groove ________
Welding Progression ________
Other ________

PREHEAT
Preheat Temp ________
Interpass Temp ________
Preheat Maintenance ________
Other ________

POSTWELD HEAT TREATMENT
Temperature ________
Time Range ________
Other ________

GAS
Shielding Gas(es) ________
Percent Composition (mixtures) ________
____
Flow Rate ________
Gas Backing ________
Trailing Shielding Gas Composition ________
____
Other ________

ELECTRICAL CHARACTERISTICS
Current AC or DC ________ Polarity ________
Amps (Range) ________ Volts (Range) ________
Other ________

TECHNIQUE
String or Weave Bead ________
Orifice or Gas Cup Size ________
Initial & Interpass Cleaning (Brushing, Grinding, etc) ________
____
____
Method of Back Gouging ________
Oscillation ________
Contact Tube to Work Distance ________
Multiple or Single Pass (per side) ________
____
Multiple or Single Electrodes ________
Travel Speed (Range) ________
Manual, Semi-Automatic or Machine Automatic ________
Other ________

Figure 28-5-1 Typical Format of Welding Procedure Specification

governed the installation welding. Similarly, nondestructive test records would identify the welding procedure specification number. In this manner, a cross reference is maintained to the records that prove the qualification of the welding procedure qualification.

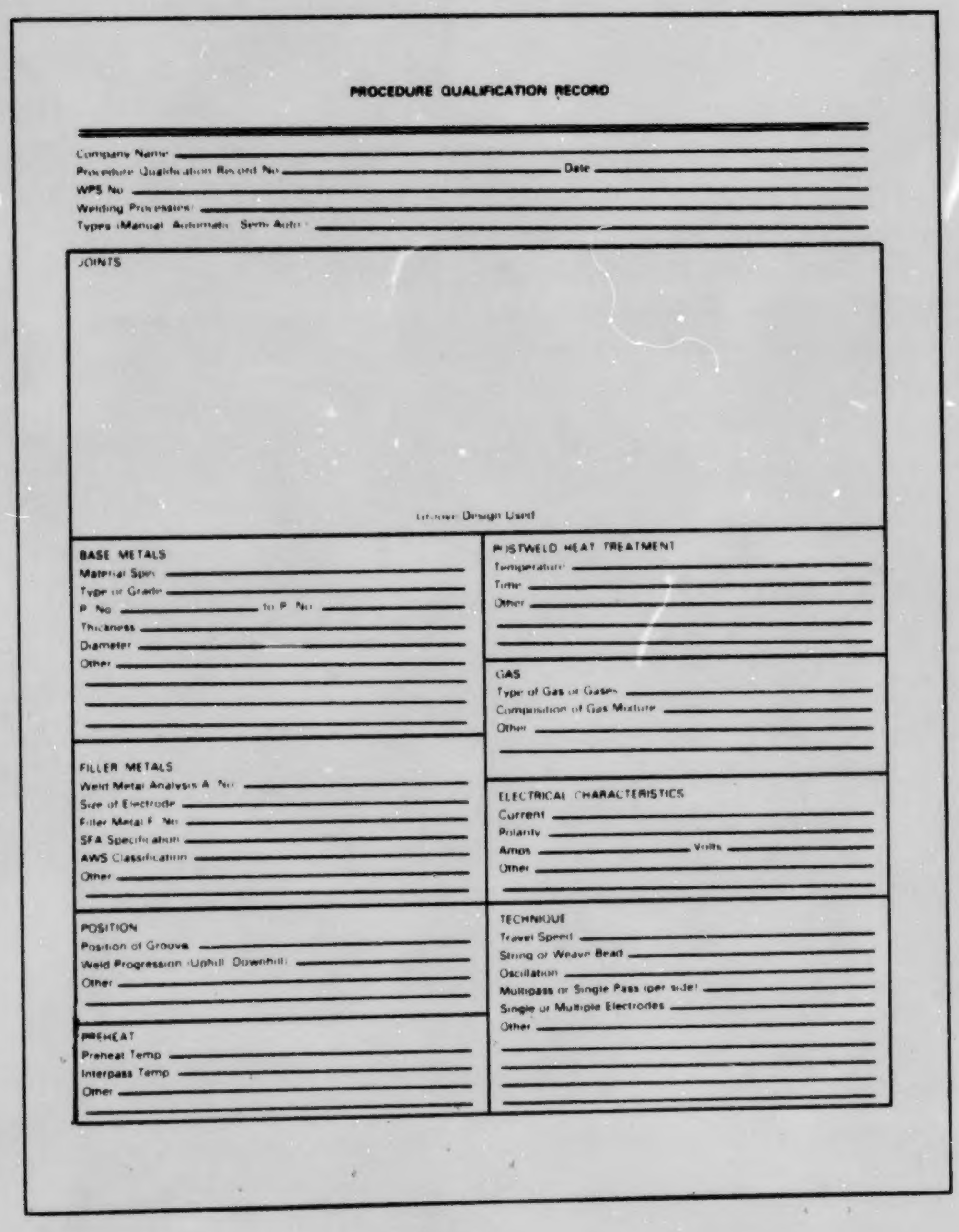
Procedure Qualification Record

When the welding procedure specification is qualified, a record of the qualification tests is made to provide objective evidence at any future time of the qualification. This procedure qualification record is uniquely serialized as previously discussed and is centrally filed to permit convenient access at any time. A typical format for the procedure qualification record is given in Figure 28-5-2.

As illustrated in Figure 28-5-2, space is provided at the top of the procedure qualification record to identify the record number and the welding procedure specification number. Again, the cross reference between these documents is maintained.

Entries recorded on the procedure qualification record reflect the actual practices employed in welding and testing the qualification test piece. The QA/QC Technician is typically responsible for making these entries or reviewing the record for completeness and acceptability of the entries.

As discussed later in this module, a single procedure qualification record can support the qualification of more than one welding procedure specification. For example, if two welding procedure specifications contain identical essential elements but different nonessential elements, one qualification test piece and corresponding procedure qualification record would support the qualification of both. In this example, the same welding process must have been used in both cases because the welding process is always considered an essential element.



PROCEDURE QUALIFICATION RECORD

Company Name ____
Procedure Qualification Record No ____ Date ____
WPS No ____
Welding Process(es) ____
Types (Manual, Automatic, Semi-Auto) ____

JOINTS

Groove Design Used

BASE METALS
Material Spec ____
Type or Grade ____
P No ____ to P No ____
Thickness ____
Diameter ____
Other ____

FILLER METALS
Weld Metal Analysis A No ____
Size of Electrode ____
Filler Metal F No ____
SFA Specification ____
AWS Classification ____
Other ____

POSITION
Position of Groove ____
Weld Progression (Uphill, Downhill) ____
Other ____

PREHEAT
Preheat Temp ____
Interpass Temp ____
Other ____

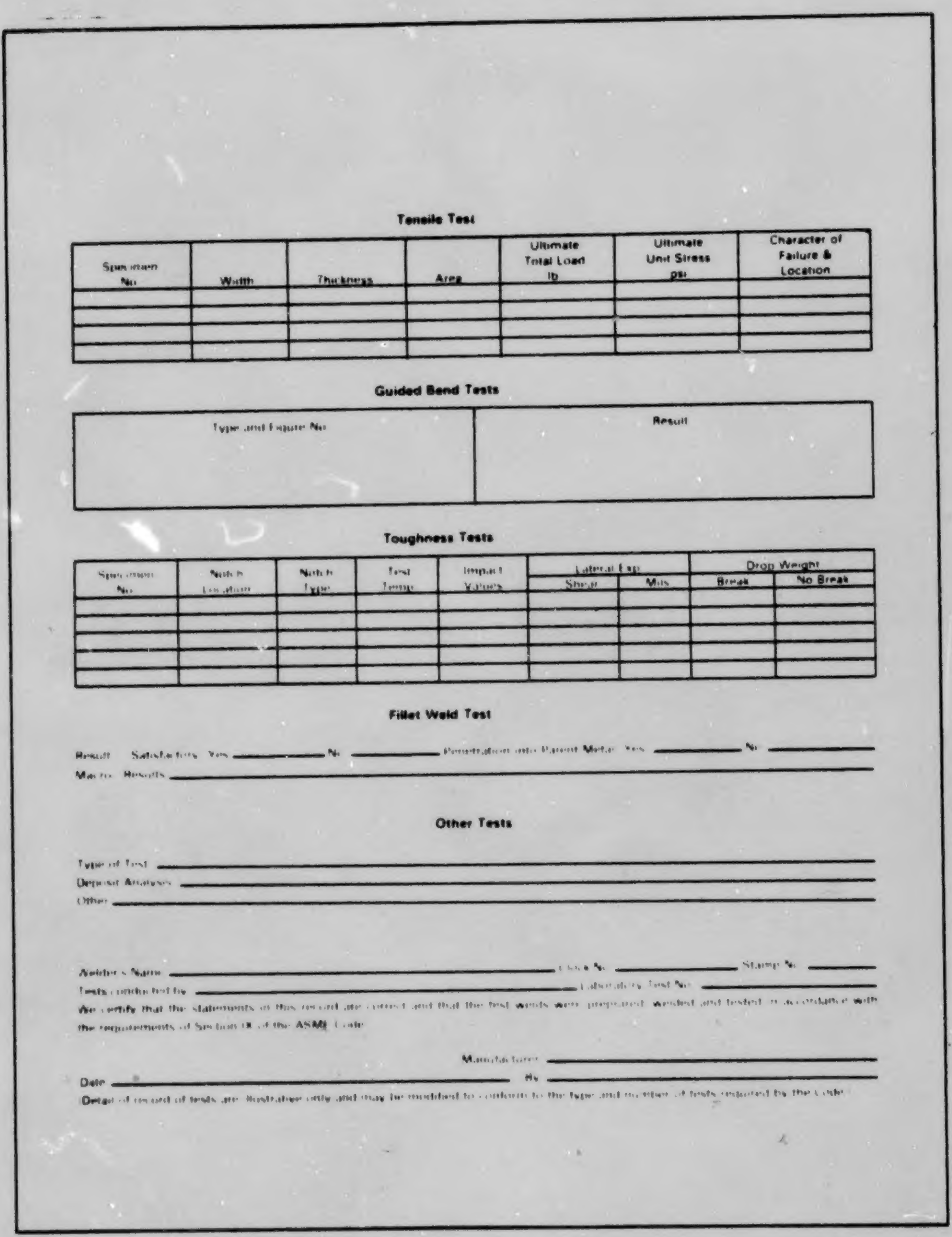
POSTWELD HEAT TREATMENT
Temperature ____
Time ____
Other ____

GAS
Type of Gas or Gases ____
Composition of Gas Mixture ____
Other ____

ELECTRICAL CHARACTERISTICS
Current ____
Polarity ____
Amps ____ Volts ____
Other ____

TECHNIQUE
Travel Speed ____
String or Weave Bead ____
Oscillation ____
Multipass or Single Pass (per side) ____
Single or Multiple Electrodes ____
Other ____

Figure 28-5-2a Sample Format for Procedure Qualification Record



Tensile Test

Specimen No.	Width	Thickness	Area	Ultimate Total Load lb	Ultimate Unit Stress psi	Character of Failure & Location

Guided Bend Tests

Type and Figure No.	Result

Toughness Tests

Specimen No.	Notch Location	Notch Type	Test Temp.	Impact Values	Lateral Exp.		Drop Weight	
					Shear	Mils	Break	No Break

Fillet Weld Test

Result — Satisfactory: Yes ________ No ________ Penetration into Parent Metal: Yes ________ No ________

Macro — Results ____________________

Other Tests

Type of Test ____________________

Deposit Analysis ____________________

Other ____________________

Welder's Name ____________________ Clock No. ________ Stamp No. ________

Tests conducted by ____________________ Laboratory Test No. ________

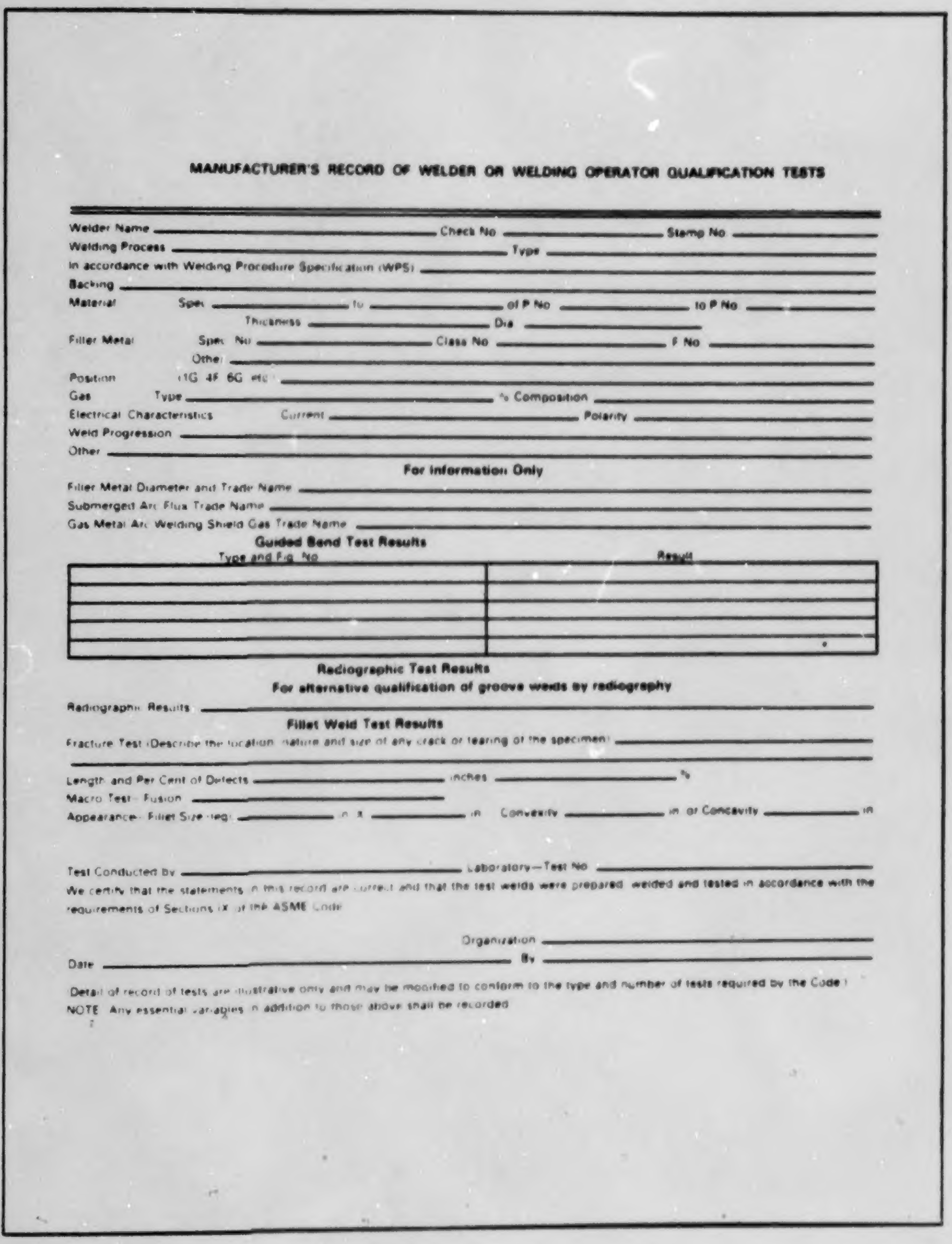
We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

Manufacturer ____________________

Date ____________________ By ____________________

Detail of record of tests are illustrative only and may be modified to conform to the type and number of tests required by the Code.

Figure 28-5-2b Sample Format for Procedure Qualification Record



MANUFACTURER'S RECORD OF WELDER OR WELDING OPERATOR QUALIFICATION TESTS

Welder Name ______ Check No ______ Stamp No ______
Welding Process ______ Type ______
In accordance with Welding Procedure Specification (WPS) ______
Backing ______
Material Spec ______ to ______ of P No ______ to P No ______
Thickness ______ Dia ______
Filler Metal Spec No ______ Class No ______ F No ______
Other ______
Position (1G 4F 6G etc) ______
Gas Type ______ % Composition ______
Electrical Characteristics Current ______ Polarity ______
Weld Progression ______
Other ______

For Information Only

Filler Metal Diameter and Trade Name ______
Submerged Arc Flux Trade Name ______
Gas Metal Arc Welding Shield Gas Trade Name ______

Guided Bend Test Results

Type and Fig. No	Result

Radiographic Test Results

For alternative qualification of groove welds by radiography

Radiographic Results ______

Fillet Weld Test Results

Fracture Test (Describe the location, nature and size of any crack or tearing of the specimen) ______
______
Length and Per Cent of Defects ______ inches ______ %
Macro Test—Fusion ______
Appearance—Fillet Size (leg) ______ in x ______ in Convexity ______ in or Concavity ______ in

Test Conducted by ______ Laboratory—Test No ______

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Sections IX of the ASME Code

Organization ______
Date ______ By ______

(Detail of record of tests are illustrative only and may be modified to conform to the type and number of tests required by the Code.)

NOTE Any essential variables in addition to those above shall be recorded

Figure 28-5-3 Typical Format for Welder Qualification Record

Welder Qualification Record

The welder qualification record gives objective evidence that a welder is qualified. (For this course, welder is used to mean both a welder and a welding operator. Most welding codes define a welder as one who is capable of performing a manual or semi-automatic welding operation. The codes define welding operator as one who operates machine or automatic welding equipment. For code requirements that do not apply equally to a welder and a welding operator, the more stringent requirements apply to the welder.) The individual who welds the welding procedure specification qualification test piece becomes qualified if the procedure is qualified. Each additional welder who will use the same welding procedure specification, makes additional test pieces. On a large job, 100 or more welders could be qualified for a given welding procedure specification. Also, as described later in this module, the welder qualification on one procedure can be valid for many other procedures. Accordingly, the easiest administrative system for keeping track of who is qualified for what is by a log book or computerized listing. The log lists for each welding procedure specification serial number, the names or stamp numbers for all welders qualified for that procedure. Individual welder qualification records are filed by name or stamp number and can be reviewed to confirm the accuracy of the log.

Qualification Test Piece (Coupon)

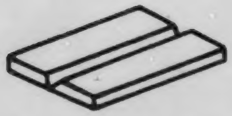
The governing welding code specifies the requirements for welding the qualification test piece. These requirements have the objective of producing a test piece that is directly representative of the weld that would be produced when the welding procedure specification is used in the sary numbers of qualification test pieces. For example, any of the materials listed in Table 28-5-1 qualifies the other materials under the same "P" number. (Table 28-5-1 is a partial listing taken from ASME Boiler and Pressure Vessel Code.)

- Base Material Thickness - As thickness of a weld joint increases, it becomes somewhat more difficult to make a quality weld. As thickness increases, more passes are necessary with attendant increases in the number of meltings and resolidifications. Also, the larger mass of surrounding material tends to increase the thermal gradient. These factors increase susceptability to cracking and other weld defects. Therefore, welding codes typically require the qualification test piece to be essentially as thick as the material to be welded in the shop or field. For example, the ASME Boiler and Pressure Vessel Code specifies three types of conditions for thickness of the qualification test piece. For the various condition, the qualification test piece must be either 50%, 90% or 100% of the weld joint material thickness.
- Position - The OA, SMA, TIG, and MIG welding processes are so adaptable to all positions that position of the qualification test piece is of little importance to procedure qualification. For this reason, position of the qualification test piece is not specified except for welds that require impact testing as part of the qualification. In such cases, vertical position with uphill progression requires separate qualification. However, position greatly influences the techniques employed by a welder. Therefore, the position used during qualification must be equivalent to the position that the welder will use in the shop or field.

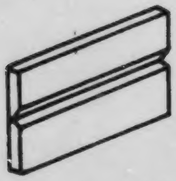
shop or field. If this representative weld passes the qualification tests, it is logical to assume that satisfactory shop and field welds will result from use of the welding procedure specification.

Requirements for the qualification test piece typically encompass joint design, material type, base material thickness, and heat treatment. These are generally as follows:

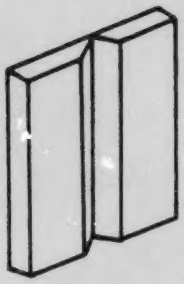
- Joint Design - Joint design (excluding thickness) is not an essential variable for welding procedure specification qualification for OA, SMA, TIG, MIG and SAW. This is because these welding processes are adaptable to all types of joints. The typical requirement is only that the type of joint specified in the procedure is used in the qualification test piece. For example, if the procedure calls for a double U groove, the test piece should have a double U groove weld preparation. However, the use of backing in a joint does influence the techniques used by welders. Therefore, for welder performance qualification, backing must be used with the qualification test piece if backing is specified in the welding procedure specification.
- Material Type - The material type for both base materials and filler materials directly influence weldability and resultant strength of the weld. For this reason, the qualification test piece and filler materials used in the procedure and the welder performance qualification must be of the same "family" of material as specified by the welding procedure specification. Family of materials refers to groupings of similar materials made by all welding codes. Such groupings consider the weldability and chemical similarity of materials and avoid unneces-



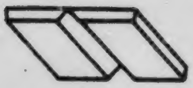
a. 1G, Flat



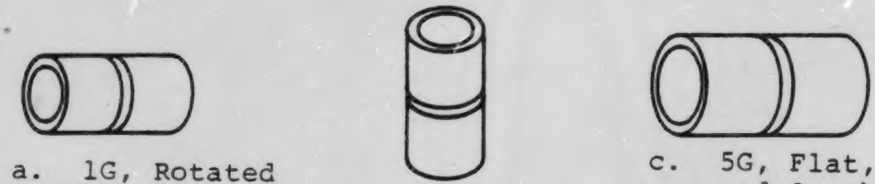
b. 2G, Horizontal



c. 3G, Vertical



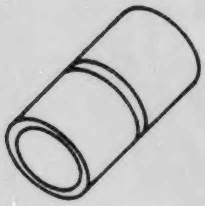
d. 4G, Overhead



a. 1G, Rotated Flat

b. 2G, Horizontal

c. 5G, Flat, Vertical and Overhead



d. 6G, All

Figure 28-5-4 Test Positions for Groove Welds in Pipe

Table 28-5-1

Grouping of Base Metals for Qualification		
P No.	Base Metal Specification	Nominal Composition
1	SA-283	Carbon Steel Plate
1	SA-675	Carbon Steel Bar
1	SA-524	Carbon Steel Pipe
3	SA-533	Low Alloy Plate
3	SA-541	Low Alloy Forgings
8	SA-240	Austenitic Stainless Steel Plate
8	SA-249	Austenitic Stainless Steel Tubes
8	SA-336	Austenitic Stainless Steel Forgings
43	SB-163	Ni-Cr-Fe Condenser Tubes
43	SB-166	Ni-Cr-Fe Rod, Bar
43	SB-167	Ni-Cr-Fe Pipe, Tube

Equivalency of position is based on the degree of difficulty in making the weld. More difficult positions qualify the welder not only for the position used for the qualification test piece but also for the less difficult positions. Figure 28-5-4 illustrates the positions for pipe and plate given by ASME Boiler and Pressure Vessel Code.

maintaining preheat and interpass temperatures during welding of the qualification test piece. Nonetheless, most companies have the policy to control these temperatures during qualification welding specified in the welding procedure specification in order to instill the practice of procedural compliance.

Post weld heat treatment has the purpose of obtaining the desired metallurgical properties in the weld. Therefore, for qualification of welding procedure specifications, welding codes require the welded test piece to be subjected to the same post weld heat treatment as specified for the shop or field weld. Tests performed on the test piece are done after heat treatment. For welder qualifications, welding codes typically permit (but not require) post weld heat treatment of the qualification test piece when post weld heat treatment is specified by the welding procedure specifications. As with preheat and interpass temperatures, such permissiveness is based on the increased probability of failure if post weld heat treatment is not used.

QUALIFICATION TESTS

Test Piece

The governing welding code specifies the required tests and the acceptance criteria for each test for qualification of both welding procedure specifications and welders. In general, one qualification test piece supplies all necessary test specimens. In certain applications, however, more than on qualification test piece is required. For examples, qualification of tube-to-tubesheet welds uses a mockup consisting of ten welds, automatic seal welding requires six consecutively welded test pieces, and manual seal welding

As shown in Figure 28-5-4, the test positions for groove welds become progressively more difficult with increasing position identification code numbers. In visualizing a welder making a weld around the stationary pipe in position 6G, one can see that all positions are represented. If it is expected that a welder would be required to weld in all positions, position 6G would be used for the qualification test piece. If a welder could not qualify in position 6G but could quality in position 2G, the welder would be assigned only flat and horizontal welding. Table 28-5-2 gives representative limits of groove welding qualification based on welding pipe in the positions shown in Figure 28-5-4.

Table 28-5-2

Welder Performance Qualification Limits for Groove Welds		
Position of Test Pipe	Positions Qualified	
	Plate	Pipe
1G	1G	1G
2G	1G, 2G	1G, 2G
5G	1G, 3G, 4G	1G, 5G
6G	All	All

- Heat Treatment - There are three types of temperature controls associated with welding: preheat, interpass and post weld heat treatment temperatures. Of these three, preheat and interpass temperatures are controlled specifically to prevent welding defects. If either of these controls are not used during qualification welding, the probability of failure increases. Therefore, welding codes normally do not require

Table 28-5-3

Procedure Qualification Mechanical Tests (Typical)						
Thickness, t, of Test Piece	Material Thickness Qualified		Number and Type of Tests			
			Tension	Transverse Bend		
	Min.	Max.		Side	Face	Root
< 1/16 inch	t	2t	2		2	2
1/16 - 3/8 inch	1/16	2t	2		2	2
> 3/8 < 3/4 inch	3/16	2t	2		2	2
> 3/4 inch	3/16	2t	2	4		

Table 28-5-4

Welder Qualification Mechanical Tests (Typical)					
Thickness, t, of Test Piece	Material Thickness Qualified		Number and Type of Tests Transverse Bend Tests		
	Min.	Max.	Side	Face	Root
1/16 - 3/8 inch	1/16	2t		1	1
> 3/8, < 3/4 inch	3/16	2t		1	1
3/4 inch and over	3/16	t	2		

requires two test pieces. Thus, each application requires research of the governing welding code to determine the required number of test pieces to be welded.

Mechanical Tests

Qualification of welding procedure specifications involve three mechanical tests: tension, bend, and impact. Tension and bend tests are normally required by welding codes for each qualification. Impact tests are required only in applications where notch toughness is important to the function of the welded item. For example, reactor pressure vessel welds are subjected to impact tests during qualification because of the need to insure that brittle fracture will not occur during reactor startup and operation. Typical numbers of tension and bend tests per qualification test piece are shown in Table 28-5-3 for procedure qualification and Table 28-5-4 for welder qualification.

Impact tests are required for procedure qualification whenever the base material specification applicable to the metals to be joined by welding require impact testing. When applicable, three impact test specimens are normally required. Two specimens are removed from the test piece such that they represent the weld metal. The other specimen is cut from the heat affected zone.

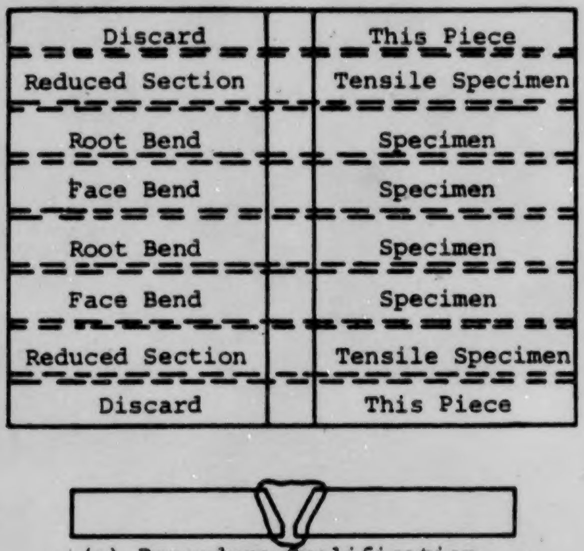
Typical locations from which tension and bend test specimens are cut are illustrated in Figure 28-5-5.

Mechanical tests determine the strength of the weld. In general, the weld must be as strong as the base metal as determined by the mechanical tests. Specific requirements are given by the applicable welding code.

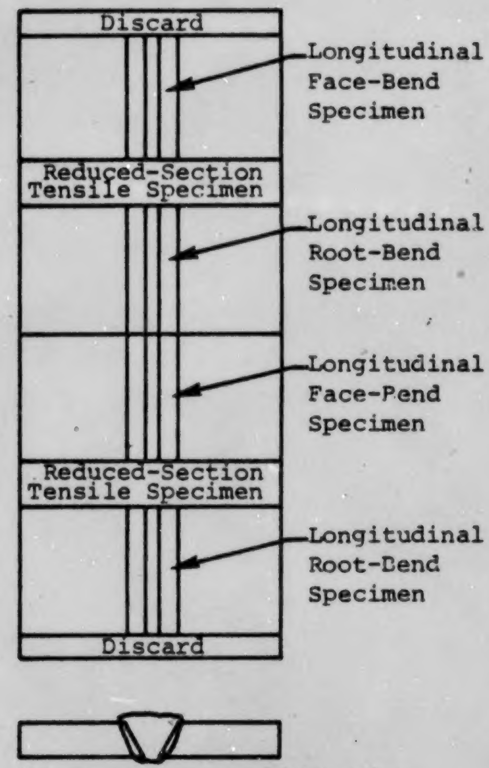
Tension tests determine the ultimate strength of the welds. Dependent on the test piece thickness, and the requirements of the governing welding code, the tension test specimen may be full thickness or reduced thickness specimens. Tension tests are required for procedure qualification but not for welder qualification. This is because improper welder techniques would be revealed by other tests and the ultimate strength of the weld will not vary substantially if the procedure is not changed. Typical acceptance criteria found in the governing welding code are as follows for the tension tests:

- minimum tensile strength equal to or greater than that of the base metal.
- minimum tensile strength equal to or greater than the weaker base material for test pieces representing the joining of base metals of different strength.
- tensile specimen breaking in the base metal and outside of the fusion line provided the strength is not more than 5% less than the specified minimum tensile strength of the base metal.

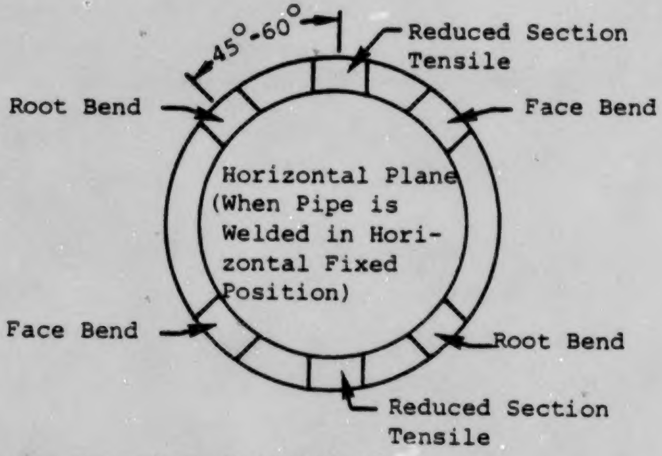
Bend tests determine the soundness (lack of welding defects) and the ductility of the weld. Normally, transverse bend tests are performed, i.e., the weld is transverse to the longitudinal axis of the test specimen. However, when bending properties differ markedly between either the two base metals or the weld metal and base metal, longitudinal tests may be performed. The longitudinal bend test specimen has the weld metal parallel to the longitudinal bend test specimen (i.e., the specimen consists of weld metal, fusion zone, and heat affected zone). Regardless of whether transverse or longitudinal bend tests are performed, the weld metal and heat affected zone must lie completely within the bent portion of the specimen after testing. Acceptance criteria consist of limits on visually discernable openings in the convex surface of the bent specimen. A typical limit is no open defect exceeding 1/8 inch as measured in any direction. Such limits apply to each of the three bend test methods.


Discard
This Piece
Reduced Section
Tensile Specimen
Root Bend
Specimen
Face Bend
Specimen
Root Bend
Specimen
Face Bend
Specimen
Reduced Section
Tensile Specimen
Discard
This Piece

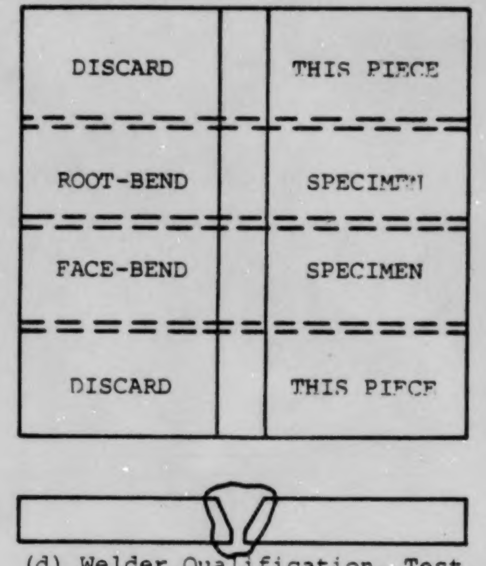
(a) Procedure Qualification, Transverse Test Specimens in Plate


Discard
Longitudinal Face-Bend Specimen
Reduced-Section Tensile Specimen
Longitudinal Root-Bend Specimen
Longitudinal Face-Bend Specimen
Reduced-Section Tensile Specimen
Longitudinal Root-Bend Specimen
Discard

(b) Procedure Qualification Longitudinal Test Specimens in Plate


45°-60°
Reduced Section Tensile
Root Bend
Face Bend
Horizontal Plane (When Pipe is Welded in Horizontal Fixed Position)
Face Bend
Root Bend
Reduced Section Tensile

(c) Procedure Qualification, Test Specimens in Pipe


DISCARD
THIS PIECE
ROOT-BEND
SPECIMEN
FACE-BEND
SPECIMEN
DISCARD
THIS PIECE

(d) Welder Qualification, Test Specimens in Plate

Figure 28-5-5 Typical Location of Test Specimens

Bend test specimens are prepared by cutting the test piece to form specimens of rectangular cross section. For side bend tests, the specimen is cut transverse to the weld such that a transverse cross-section of the weld is tested. For face and root bend tests, the specimen is cut transverse or longitudinal to the weld, whichever is specified. In either instance, face bend tests require the weld face to become the convex surface after testing. Similarly, the root becomes the convex surface after root bend testing.

Impact tests determine the notch toughness of the weld. When impact testing is required, test specimens are removed from the weld metal and the heat affected zone at a depth of 1/4 t or more where t equals base metal thickness. Each specimen is tested at a temperature that is equal to or lower than the lowest service temperature specified for the welds. Acceptance criteria consist of limits on absorbed energy and dimension of lateral expansion of the broken specimen.

Special Tests

In nuclear power plant welding, certain welds are specially designed for unique purposes. In such cases, special tests are performed to qualify the procedure and welder. These special welds are (1) tube-to-tubesheet welds, (2) hardsurfacing, and (3) weld deposited cladding.

Tube-to-tubesheet welds are formed in steam generators and in certain other heat exchangers. Manufacturers of these components are normally responsible for these welds. Access for nondestructive examinations is severely limited due to the close proximity of thousands of tubes in the tubesheet. Qualification of the welding procedure and welder is based on welding a number of tube test pieces followed by liquid penetrant examination and sectioning of the welds. The sectioned specimens are polished and visually examined for cracks at high magnification.

Hardsurfacing by welding is employed on a number of components having moving surfaces in contact during service. Qualification of the welding procedure and welder is based on welding a test piece that is subjected to liquid penetrant examination, sectioning, hardness testing, and chemical analysis. The sectioned test specimen is polished and visually examined at magnification for cracks in the bond line. The hardness test determines that the desired wear properties have been obtained. The chemistry test determines that little diffusion of base metal into the hardsurface deposit has occurred.

Weld deposited overlay cladding is employed for many components to provide a surface that is corrosion resistant. For example, the inside surfaces of a low alloy steel reactor pressure vessel is clad with stainless steel or nickel-chrome-iron alloys to give excellent resistance to corrosion. Qualification of these welding procedures and welders is based on depositing cladding on a flat block which is subjected to liquid penetrant examination and side bend tests.

Substitution of Radiography for Mechanical Tests

For qualification of welders (not procedures), welding codes permit deleting mechanical tests and substitution of radiographic examination in certain cases. For example, the ASME Boiler and Pressure Vessel Code generally permits substitution of radiography for mechanical tests for the qualification of welders for all types of carbon steel and low alloy steel base metals. When this option is employed, the qualification test piece is radiographed and the radiograph is viewed for indication of welding defects. Also, in lieu of a test piece, the welder's first production piece can be radiographed to determine qualification. Typical acceptance criteria are (1) no indication of a crack, (2) no slag in excess of (length) (typically between 1/8 and 3/4 inch dependent on base material thickness), and (3) no more than (number) of rounded indications and no rounded indication larger than (size).

REQUALIFICATION

General

Once the welding procedure specification is qualified, it need not be requalified unless essential variables of the procedure are changed. Welders, however, need to periodically demonstrate their proficiency in welding. Such demonstration may be by performance of welding on the job. Therefore, formal requalification of welders is required only when the welder has not used the particular welding process for a considerable time period or when there is specific reason to question the welder's ability to make a sound weld.

Essential Variables for Procedure Qualification

The initial qualification of a welding procedure specification is valid until such time as essential variables are changed. Such changes give different weld properties in the final weld. Such changes may be to a given procedure or may be considered in a new procedure. When a new procedure is prepared it is compared with similar, existing, qualified procedures. If the new procedure contains values for essential variables that are within the range of those qualified, the new procedure is considered as qualified. In such event, the supporting Procedure Qualification Record serial number is entered on the new procedure. If a revised procedure or a new procedure contain values for essential variables outside the range of those qualified, a new qualification is performed.

The governing welding code specifies for each welding process the applicable essential variables and the range of values beyond which requalification is required. The welding engineer is normally responsible for determining when requalification is required and for preparing the instructions for carrying out the requalification. The QA/QC Technician is normally responsible for monitoring the requalification effort to assure compliance with the welding code.

Typical changes to essential variables for OA, SMA, TIG, MIG and SAW welding processes that require requalification of the procedure are given in Table 28-5-5.

Essential Variables for Welder Qualification

For each welder qualification, the welder must periodically use the welding process or be requalified. Use of the process at least once per each six month period "maintains" the welder's qualification. Less frequent use requires requalification.

A welder who is qualified for a given welding procedure is considered qualified for all other welding procedures which employ the same welding process provided that essential variables do not differ beyond limits. Typical limits for essential variables for welder qualification are given in Table 28-5-6.

ADMINISTRATIVE CONTROLS

Purpose

Welding codes require certain administrative controls to permit review of qualification status at any time. These

Table 28-5-5

Change in Essential Variables Affecting Procedure Qualification					
Change to Essential Variable	Welding Process				
	OA	SMA	TIG	MIG	SAW
Base Metals					
- change in base metal types	X	X	X	X	X
- increase in base metal thickness beyond that qualified	X	X	X	X	X
Filler Materials					
- change in filler material type	X	X	X	X	X
- change in chemical composition of weld deposit	X	X	X	X	X
- change in flux classification					X
- addition or deletion of consumable inserts			X		
- deletion or addition of filler material			X		
- change in consumable electrode from bare to flux cored, flux covered or vice versa				X	
- addition, deletion or increase in amount of supplementary powdered filler material					X
Position					
- when impact test is required, a change from any position to the vertical uphill progression		X	X	X	
Preheat					
- a decrease of more than 100°F in specified preheat		X	X	X	X
Post Weld Heat Treatment					
- a change in temperature range	X	X	X	X	X
- for austenitic stainless steel, the addition or deletion of a solution or stabilizing heat treatment		X	X	X	X
- when lower critical temperature is exceeded, an increase in base metal thickness beyond 1.1 times the thickness of the qualified test coupon		X	X	X	X

Table 28-5-5 (Continued)

Change in Essential Variables Affecting Procedure Qualification					
Change to Essential Variable	OA	SMA	TIG	MIG	SAW
Gas					
- a change in the type of fuel gas	X				
- a change in type of gas or to a mixture, or change in percentage of mixture			X	X	
Electrical Characteristics					
- when impact testing is required, a change in type or polarity of current or an increase in voltage or amperage		X	X	X	X
Technique					
- when impact testing is required:					
- a change in pulsing frequency duration			X	X	X
- a change in arc timing of more than ± 10%			X	X	X
- a change in amperage of more than ± 10%			X	X	X
- a change from upward to downward or vice versa for the vertical position		X	X	X	
- for thickness less than 1 1/2 inches, an increase in volume of weld metal deposited beyond that qualified		X	X	X	X

Table 28-5-6

Change in Essential Variables Affecting Welder Qualification

Change to Essential Variable	OA	SMA	TIG	MIG	SAW
Joint					
- deletion of backing ring in single welded butt joints		X	X	X	
- addition of backing	X				
Base Metal					
- a change in base metal thickness beyond the range qualified	X	X	X	X	X
Filler Material					
- a change in type of filler material	X	X	X	X	
- addition or deletion of consumable inserts					
Position					
- addition of a position other than that qualified for	X	X	X	X	X
Gas					
- a change in type of fuel gas	X				
- deletion of gas backing			X	X	
Electrical Characteristics					
- a change from spray arc, globular arc, or pulsating arc to short circuiting arc or vice versa				X	
- a change from AC to DC or vice versa; a change from straight polarity to reversed polarity or vice versa			X		
Techniques					
- a change from upward to downward progression or vice versa for the vertical position				X	

controls pertain to transfer of qualifications, identification of welding procedure to each weld joint and identification of welders to each weld joint.

Transfer of Qualification

Most welding codes prohibit the transfer of qualification from one organization to another. Therefore, each organization (company) must qualify the welding procedures and the welders employed by that company. This is based on the premise that each company is responsible for its welding and it is therefore, incumbent on the company to qualify their welding procedures and welders. For those welding codes that do permit transfer of qualification, the company must obtain actual qualification test documentation to support the transfer of qualification.

Identification of Welding Procedure to Weld Joint

The welding procedure used in making a weld must be retrievable at a future time. To make provision of this, weld inspection reports (normally completed by the QA/QC Technician) identify the weld joint number and the number of the welding procedure specification that was used in making the weld. As described previously in this module, the welding procedure specification in turn references the procedure qualification record. These documents provide objective evidence that a qualified welding procedure was used.

Identification of Welder to Weld Joint

One of two methods may be used to identify the welder to each weld joint. First, uniquely serialized stamps may be issued to each qualified welder. The welder stamps on or adjacent to each of his or her welds. Secondly, the weld inspection report may identify the weld joint and the welder by name or number. In either method, all welders making a given weld must be identified.

To assist in assuring assignment of only qualified welders, most welding department managers maintain a folder or logbook for each welder. The folder or logbook contains or references for each welder the welder qualification records and times that welders performed welding. Such documentation enables the manager or lead person to quickly determine who is qualified for what and whether such qualification has been maintained through production welding.

EXERCISE

The following exercises should be completed as a means of reinforcing the concepts presented in this module.

1. Referring to the text and Table 28-5-5 or Table 28-5-6 as appropriate, determine if requalification is necessary for each of the following conditions. Explain response.
    a. A welder is qualified in the 6G position for a metal inert gas welding procedure. Would the welder need to be requalified for the 2G position for a tungsten inert gas welding procedure if all other essential variables remained the same?
    b. A shielded metal arc welding procedure is qualified. Would another shielded metal arc welding procedure need to be qualified by welding a test piece if it differed from the qualified procedure only as follows: change in current from 80 amps to 75 amps, change from flat to horizontal position and change from V groove to U groove?

c. A welder makes a procedure qualification test piece for a submerged arc welding procedure. The test results are satisfactory and the procedure is qualified. Would the welder be required to weld another test piece to become qualified for this procedure?

d. A qualified metal inert gas welding procedure is revised to change the arc transfer mode from spray arc to globular arc. Is requalification of the procedure required?

e. A qualified oxyacetylene welding procedure is revised to change from a neutral flame to a carburizing flame. Is requalification of the procedure required?

f. A qualified tungsten inert gas welding procedure is revised to change gas flow from 15 to 12 ft^3/hr, current from 45 to 42 amps, voltage from 12 to 10 volts and bare spooled wire to bare straight rod. Is requalification of the procedure required?

2. The following statements summarize the major points of this module. Place a check by each point as you recall it.

___ The specific number of qualification test pieces and the number and type of test specimens to be cut from each piece are specified by the governing welding code.

___ The three types of mechanical tests are tension, bend and impact.

___ Procedure qualification test pieces are normally subjected to tension and bend tests.

___ Impact tests are performed when the specification for the base material requires impact testing.

___ For procedure qualification, two tension and four bend tests are normally required.

___ Tension tests determine the strength of the weld. Bend tests determine the soundness and ductility of the weld. Impact tests determine the toughness of the weld.

___ Tension tests are not required for welder qualification because qualification of the procedure determined weld strength and the bend tests (or radiography) will indicate welder induced defects.

___ For side bend tests, one or the two cut surfaces becomes the convex surfaces after testing.

___ For face bend tests, the surface of widest weld width becomes the convex surface after testing.

___ For root bend tests, the surface of the narrowest weld width becomes the convex surface after testing.

3. Perform the three projects outlined in the PROCEDURES section of this Module. These are:
    a. Research the qualification requirements for a specific welding project
    b. Go on a tour of a welding qualification shop.
    c. Review administrative procedures for qualifying welders.

MATERIALS

The following materials are required to support this module:

1. ASME Boiler and Pressure Vessel Code, Section IX, Welding Qualifications (Reference copy)

2. AWS Structural Welding Code, AWS D1.1 (Reference Copy)
3. Industry administrative procedure for qualifying welding procedures and welders

PROCEDURES

1. Research a project to determine specific qualification requirements for a given welding process. Given information from the instructor should include title of welding code, name of welding process, values for essential and nonessential variables, and whether qualification requirements for procedure, welder, or both are to be determined. The given information could be an actual welding procedure specification obtained from a welder training program or from industry.
2. Go on a guided tour of a welding qualification shop. Complete Data Table 28-5-1 "Tour of Welding Qualification Shop" either during or after the tour. Discuss completed forms in class.
3. Review industry administrative procedures for qualifying welders and welding procedures against the applicable welding code. Obtain from the instructor copies of the administrative procedures and the applicable welding code. Identify key procedural controls and state if the procedure complies with the welding code.

DATA TABLE

Data Table 28-5-1
TOUR OF WELDING QUALIFICATION SHOP

As you go through the welding qualification shop, observe as many of the items on this data table as possible. Answer the questions or fill in the information that is requested.

1. Welding Process (check one)
   - ___ oxyacetylene
   - ___ shielded metal arc
   - ___ tungsten inert gas
   - ___ metal inert gas
   - ___ submerged arc
   - ___ other (specify)

2. Qualification is for procedure/welder (circle one)

3. base metal type ____________________
   joint design ____________________
   backing ____________________
   position ____________________
   current ______ AC ______ DC ______ Straight ______
   ______ Reversed ____________________
   voltage ____________________
   shielding ____________________
   filler material ____________________
   consumable insert ______ Yes ______ No ______

4. Test Specimens
   Sketch the test piece and indicate from where each specimen was obtained. Label each specimen by type of test.

5. Post Weld Heat Treatment

Used__________Yes __________No

Temperature range ____________________

All tests done after heat treatment_________Yes

__________No

6. Mechanial Tests

Check all that are applicable.

___ tensions

___ root bend

___ side bend

___ hardness

___ face bend

___ impact

Tensile Test

2% offset method__________Yes __________ Not Used

Tensile strength__________________

Acceptable ______________Yes ___________ No

Hardness Test

Type ____

Value ____

Acceptable __________ Yes _________ No

Impact Test

Type ____

Acceptable ____________ Yes __________ No

7. Chemical Test

Used ___________ Yes ____________ No

Type ____

Acceptable ____________Yes _____________ No

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8. Radiography

Used ____________Yes __________ No

Indications ____

Acceptable ____________ Yes __________ No

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Sections III and IX, 1979, American Society of Mechanical Engineers

AWS, Structural Welding Code, AWS D1.1, American Welding Society

AWS, Reinforcing Steel Welding Code, D12.1, American Welding Society

TEST

Match the code with its application

	Codes		Applications
1.	___ ASME Boiler and Pressure Code	a.	welding of rebar in concrete
2.	___ AWS Structural Welding Code	b.	welding of mobile vehicle frames
3.	___ AWS Reinforcing Steel Welding Code	c.	welding of construction steel beams
		d.	welding of safety related piping systems

State the purpose for qualifying:

4. welding procedure specifications
5. welders
6. Describe the method used for qualifying welding procedure specifications and welders.

State the purpose of the following documents:

7. welding procedure specification
8. procedure qualification record
9. welder qualification record
10. A radiography test report identifies that a weld made by a WPS 302 is acceptable. Describe how it can be determined if a qualified procedure was used to make the weld.
11. True or False (circle correct response):
    The number of welding procedure specifications always equals the number of procedure qualification records.
12. Give the basis for your answer to question 11.

13. Five features of each qualification test piece are typically controlled by requirements of the governing welding code. Name five features.

a.

b.

c.

d.

e.

Indicate whether statements 14 through 20 are true or false.

14. ____ When a welding procedure specification for fillet welding is to be qualified, the qualification test piece should be a fillet weld.

15. ____ If the only difference among three welding procedure specifications is the material type but all three materials types are of the same "P" number, only one qualification test piece is required.

16. ____ A qualification test piece of one inch thickness is suitable for qualification of welds one inch and less in thickness.

17. ____ A welder who qualifies in the horizontal position automatically qualifies for the flat position.

18. ____ Preheating need not be used in welding procedure specification qualification.

19. ____ Tests on the qualification test piece for qualification of a welding procedure specification are conducted after heat treatment of the welded test piece.

20. ____ An essential variable is a welding parameter that requires requalification of the procedure when it is changed beyond limits.

21. Briefly describe the responsibilities of the QA/QC Technician with respect to qualifications of welding procedures.

22. Describe how to determine if a given welding procedure specification is in fact qualified.

23. If the specific person is known who made a given field weld, describe how to determine if the welder is qualified for that weld. Include significance of welding process and calendar date.

24. Even though the welding procedure specification stipulates a maximum interpass temperature, welding of the procedure qualification test piece can omit control of interpass temperature. Give the rationale for such an omission.

25. Name three types of mechanical tests used in welding procedure qualifications and state the purpose of each.

a.

b.

c.

26. Describe the physical configuration of the weld in each of the following bend specimens after bending.

    a. side bend:

    b. face bend:

    c. root bend:

NUCLEAR TECHNOLOGY

MODULE 28-6

PROCESS CONTROLS

COURSE 28 WELDING INSPECTION

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
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COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
⇨ MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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INTRODUCTION

The first five modules of this course have discussed the fundamentals of welding. It is evident that a welding program is complex, particularly when it is applied to construction or maintenance cycles employing hundreds of welders. While completed welds are examined as described in Module 28-7, examination of final welds do not provide total assurance of weld quality. Final examinations determine if welding defects are present, but it does not measure the chemical and mechanical properties of the weld. As described in Module 28-5, these properties are assumed to be correct if qualified procedures are followed by qualified welders. Use of qualified procedures by qualified welders is assured by in-process checks.

The need for in-process checks of welding is recognized by Criterion IX of Appendix B to 10CFR50. This criterion reads as follows:

> *"Measures shall be established to assure that special processes, including welding, heat treating, and nondestructive testing, are controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements."*

This criterion is met by the combination of written procedures and process control. Written procedures delineate responsibilities and authorities for the welding program. They include the welding procedure specification and instructions for procedure and welder qualification. If the procedures are adequate and if compliance with procedures is achieved, weld quality can be assured. Process control assures that procedures are adequate and are followed.

Process control is typically achieved by procedures review, process monitoring, and weld defect analysis. The QA/QC Technician is normally responsible for process monitoring and may also participate in procedures review and weld defect analysis. This module describes these functions.

MODULE PREREQUISITES

All previous Course 28 modules shall be complete before proceeding to this module

OBJECTIVES

Upon completion of this module, the student/trainee shall be able to:

1. Name five types of inspections associated with monitoring of welding processes, describe how each is conducted, and state the purpose of each.
2. Demonstrate the ability to read and interpret a post weld heat treatment chart.
3. State the objective of welding process monitoring and describe four key features which should be contained by a welding process monitoring program.
4. Name and discuss three factors which should be considered in establishing the base line frequency for monitoring welding processes.

5. Name seven elements of the administrative procedure for the welding process monitoring program and describe the role of each.
6. Name four elements of weld defect analysis and describe the role of each.
7. Relate the effectiveness of weld defect analysis to welding production rate, timeliness of analysis, and method of analysis.

NOTES TO INSTRUCTOR / STUDENT

Advance preparation will be needed for the exercises suggested by this module. In particular, example heat treatment charts will be necessary to develop skills in interpreting heat treatment charts. Nearby industries and power plants may be willing to provide example heat treatment charts.

SUBJECT MATTER

DEFINITIONS

- Review - A deliberately critical examination to determine compliance with a standard.
- Inspection - Examination, observation or measurement to determine conformance of materials, supplies, components, parts, appurtenances, systems, personnel performance, procedures, processes, or structure to predetermined requirements.
- Monitoring - Inspection of personnel performance, procedures, and processes on a job site while the process is in operation.
- Defect Analysis - A planned review of data to determine the effectiveness of a process in terms of defect rate or other indication of acceptance.

WELDING CONTROL PROGRAM

Written procedures describe the responsibilities and authorities within an organization for implementing the welding program. These procedures typically assign responsibilities to three departments: Welding Engineering, Welding (or Maintenance), and Quality Assurance. These responsibilities are typically distributed as follows:

Welding Engineering Department Responsibilities are as follows:

- define welding procedure qualification requirements
- define welder qualification requirements
- prepare welding procedure specifications
- prepare requisitions for procurement of materials and equipment

- prepare welding job packages consisting of all necessary drawings, sketches, and welding procedures to provide instructions on what to weld, when to weld, how to weld, and special instructions such as for cleaning, grinding, heat treating, etc.
- review nondestructive examination procedures
- disposition welding defects

Welding (or Maintenance) Department Responsibilities are as follows:

- perform welding procedure qualifications
- perform welder qualifications
- perform shop or field welding (original and repair)
- maintain welder requalifications
- maintain welding equipment
- prepare and implement supplementary instructions for good welding practices such as distortion control, cleaning, fit-up, temperature measuring practices, control of filler material on the job, control of hand tools such as brushes, grinders, picks, etc.

Quality Assurance Department Responsibilities are as follows:

- prepare the company's welding program control procedure
- review procedures, instructions, and requisitions prepared by Welding Engineering and Welding Departments
- review welding job packages and identify the acceptance inspections to be performed (NOTE: identification of acceptance inspections is sometimes performed by Welding Engineering and approved by Quality Assurance)
- prepare nondestructive examination procedures
- prepare or approve records formats for procedure and welder qualifications and for examination of shop and field welds

- establish and implement a weld filler material control program that issues to welders only the correct filler material (NOTE: this function is sometimes assigned to another department with Quality Assurance having a monitoring role)
- provide the qualified personnel for nondestructive examination of welds
- assure an adequate system exists for collection and storage of welding records
- develop and implement a process monitoring program

Execution of the above responsibilities should provide for adequate procedures. Each type of procedure receives an independent review prior to its use. The independent review ensures that the procedures comply with governing welding codes and regulatory requirements. Assurance of compliance with the procedures is provided by the process monitoring function.

INSPECTIONS OF PROGRESS MONITORING AND ASSOCIATED ACCEPTANCE CRITERIA

Within the process monitoring program, inspections are performed to determine compliance with procedural requirements. In this regard, inspections are performed for cleanliness, fit-up, welding data, post weld heat treatment and compliance with welding program procedures. Each of these types of inspections are discussed below.

Inspection for Cleanliness

Cleanliness inspections are visual inspections that are performed immediately prior to, and shortly after weld joint fit-up. Cleanliness of interpasses may also be inspected.

Prior to commencement of welding, cleanliness inspections ascertain that the weld end preparations and backing or consumable inserts (if used) are free from scale, rust, oil, grease, and other loose surface materials. Any of these materials could cause inclusions or porosity in the weld.

During welding, slag formed by the welding process must be removed after each welding pass. Cleanliness inspections during welding confirm adequate removal of slag and use of proper cleaning tools. In general, brushes and picks used on carbon and low alloy steels should not be used on stainless steels and nickel and copper alloys. Such use can result in free iron contamination of the speciality metals.

Cleanliness inspections are also concerned with the environment. There should be no adjacent operations such as grinding that produce quantities of airborne materials that could violate the cleanliness requirement of the weld joint. Also, welding should not occur in open spaces during rain, snow and high winds. These natural elements can cause oxidation, porosity and cracking by addition of oxygen and hydrogen and by interfering with shielding.

Inspection for Fit-Up

Fit-up inspections are visual and dimensional inspections that check joint preparation, position, restraints, base metal identity, and filler material identity. The requirements of the job package give the acceptance criteria.

As described in Module 28-4, weld joint preparations and fit-up dimensions are specified by sketches or drawings that are part of or referenced by the welding procedure or work instruction. The fit-up inspection confirms proper joint preparation, fit-up, and alignment by visually and dimensionally inspecting each drawing attribute. Fit-up inspection also checks for compliance with requirements for backing gas when used and it confirms that the fit-up has placed the weld in the specified welding position.

Visual inspection confirms compliance with specified requirements for distortion control devices. This includes clamps, braces, fixtures, and chill blocks. (When welding a thin member to a thicker member, chill blocks are placed against the thin member to dissipate heat. This reduces the tendency of the thinner member to warp. Chill blocks are typically solid copper blocks.)

Material identity is confirmed by visual inspection. Base metal identity may be ascertained from physical identity on the base metal or by paperwork accompanying the base metal. Filler material identity is physically on the filler material or its container or both. Module 28-8 gives detailed information on filler material identity.

Inspection for Welding Data

Inspections for welding data are visual inspections supplemented as necessary by measuring devices. These inspections check for compliance with the welding procedure specification.

Inspection of preheat and interpass temperature requires use of a temperature measuring device. Preheat temperature is measured on the base metal within about two inches or less of the next welding pass. Interpass temperature is measured on the previous welding pass immediately prior to depositing the next welding pass. The most commonly used inspection devices are contact pyrometers and temperature melting crayons.

Contact pyrometers are direct reading temperature gages. Placement of the sensor directly on the weld or adjacent base metal will give a temperature reading on the dial.

Temperature melting crayons are made of a composition that melts at a specified temperature. Manufacturers supply these crayons in increments of 25°F. For example, a series of crayons may have melting temperatures of 250°F, 275°F, 300°F, 325°F, etc. When measuring preheat temperature, a crayon is selected whose melting temperature equals the specified minimum preheat temperature. For example, if minimum preheat is 300°F, a 300°F crayon would be selected. If the crayon melts when marked against the base metal, it is evident that base metal temperature is greater than the specified minimum. When measuring interpass temperature, a crayon is selected whose melting temperature is equal to the specified maximum interpass temperature. If the crayon does not melt, it is evident that interpass temperature is below the maximum limit. In either case, crayon melting is observed by no visible marking on the metal. If the crayon does not melt, it physically marks the metal similar to colored chalk marking on a chalkboard.

Visual inspections are made for the remainder of the specified welding data. These inspections check for compliance with requirements for current, voltage, polarity, shielding gas, bead sequence and oscillation, flux if used, and any other specified welding data. All of these checks can normally be made by visually observing the welding equipment, gas meters, and the weld. When welding equipment does not have integral voltmeters and ammeters (or if these meters are not in the calibration program), portable tong meters are used. Tong ammeters and voltmeters contain a coil that is clamped around the welding power cable. When welding current is applied, its magnetic field is detected by the coil and reads out on the tong meter as volts or amperes dependent on the type of tong meter.

Inspection of Post Weld Heat Treatment

When post weld heat treatment is required, a heat treatment procedure (or the heat treatment section of the welding procedure specification) provides instructions for the heat treatment. These instructions typically specify the method of heating, maximum heat-up and cool-down rates, the heat treatment temperature range, and the time period for holding the weldment within the heat treatment temperature range. Visual inspections are employed to confirm compliance with these requirements.

The method of heating is specified in terms of a furnace to be used when the weld is transportable or a means of locally heating the weld. Electrical induction heating coils and gas torches are common methods of local heat treatments. Furnaces are typically electric or gas types to avoid a contaminating atmosphere in the furnace. Certain special alloys also require use of an inert gas atmosphere during heat treatment.

Heat treatment chart recorders are typically used to provide a permanent record of the heat treatment. These recorders are normally of the thermocouple-bridge type with automatic chart recorders as described in Course 3, Principles of Process Instrumentation. A typical heat treatment chart is illustrated in Figure 28-6-1.

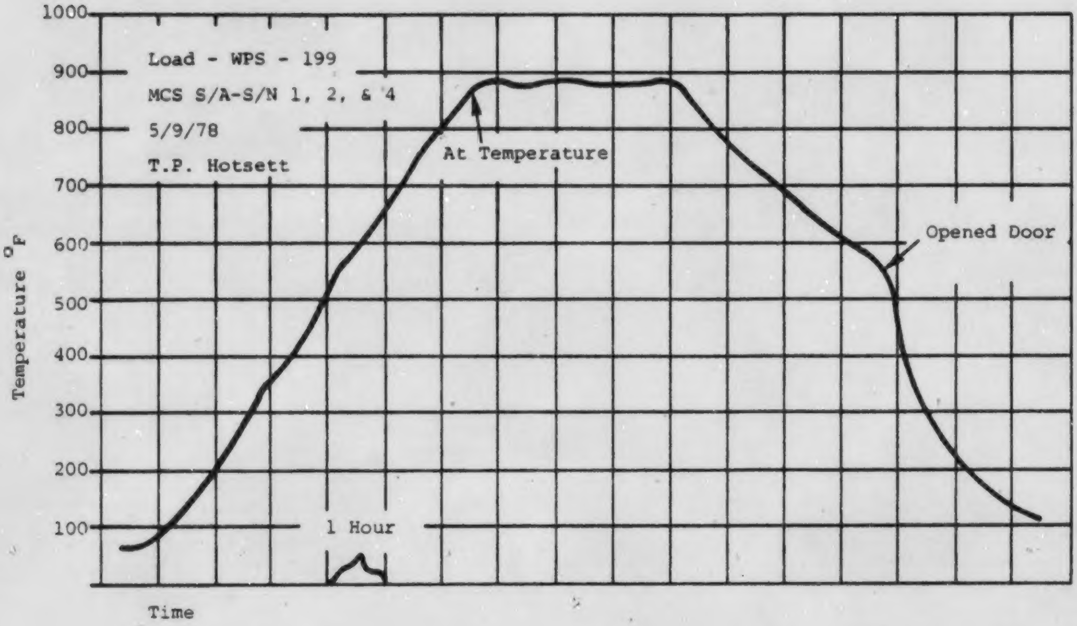

Figure 28-6-1. Typical Heat Treatment Chart

EXAMPLE REVIEW OF HEAT TREATMENT CHART

Given Procedural Requirements:

- Heat treat at 850-900°F for 1 hour per inch of thickness
- Maximum heat-up rate of 200°F/hour
- Maximum cool-down rate of 100°F/hour to 600°F

Review Using Figure 28-6-1:

1. From WPS-199 determine base metal thickness.
2. Base metal thickness = 2.75 inches.
3. Calculate time at temperature: 2.75 x 1 = 2.75 hours (minimum)
4. Read heat treat chart:
   a. Temperature is between 880°F and 895°F for 3 hours - acceptable
   b. Heat-up is from 70°F to 890°F in 5.5 hours
   c. Calculate heat-up rate = $\frac{890 - 70}{5.5}$ = 149°F/hr - acceptable
   d. Cool-down is from 880°F to 600°F in 3.3 hours
   e. Calculate cool-down rate: $\frac{880 - 600}{3.3}$ = 85°F/hr - acceptable
5. Conclusion - Heat Treatment is Acceptable

Inspections for Compliance with Welding Program Procedures

In-process visual inspections determine that welding program procedural requirements are met. These checks confirm use of the specified welding procedure, qualification of procedure and welder, completeness of the job package, and proper provision for acceptance inspections and associated records.

ESTABLISHMENT OF PROCESS MONITORING

The previous discussion points out the features and attributes of welding that are checked (inspected) in-process, i.e., while welding operations are occurring. The important question becomes how many welding operations must be inspected in-process. The answer is not absolute; it depends. The questions must be answered in qualitative terms.

Consideration of All Other Controls

In the establishment of a process monitoring program, all other quality controls and the production schedule are considered. With respect to welding program controls, the following exist:

- Written procedure that delineates responsibilities for control of welding.
- Written procedures that direct the welders, grinders, heat treaters, etc., in all pertinent requirements for making a quality weld.
- Use of qualified welding procedure specifications.
- Use of qualified welders.
- Nondestructive examination of completed welds.
- Use of qualified personnel for nondestructive examination.
- Certain in-process inspection required by applicable welding codes, (e.g., review of heat treatment charts).

From the above, the logical conclusion is that the objective of process monitoring is to provide assurance that all of the welding program controls are in place and working. Such assurance would indicate that welding defects would be prevented or at least detected.

Consideration of the Production Rate

Next, consideration is given to how much assurance is needed. Again, the answer is not absolute. The amount of monitoring is continuously assessed and adjusted in proportion to the production rate and number of deficiencies that occur. The typical process monitoring program has a "base line" amount of monitoring with provision for increasing or decreasing this amount.

The base line amount of monitoring is predicated on the production rate and the reject rate. If hundreds of welds are made per week, the amount is relatively high. On the other hand, if few welds are made per week, the amount is low. If few welding defects are occurring, the amount in both cases is lower. In establishing the base line amount of monitoring, all welding stations, welding processes, and welders should be subject to monitoring. An example of establishing a base line amount of monitoring is given on the next three pages.

EXAMPLE ESTABLISHMENT OF BASE LINE MONITORING

Research of welding schedules determines that on the average, the welding rates in number of welds per week are as follows:

WELDING PROCESS	WELDING STATIONS A	B	C	D	E	Total
OAW	10	0	0	0	0	10
SMA	30	120	40	40	0	230
TIG	0	0	80	80	0	160
MIG	0	0	80	80	0	160
SAW	0	0	0	0	20	20
TOTAL	40	120	200	200	20	580

Research of the number of qualified welders gives:

WORK SHIFT	WELDING PROCESS OAW	SMA	TIG	MIG	SAW	Total
1	2	6	4	4	4	20
2	0	2	4	4	0	10
3	0	2	4	4	0	10
TOTAL	2	10	12	12	4	40

Base Line Determination:

1. As a starting point, the objective of monitoring 10% of the welding operations is established.
2. Number to be monitored weekly based on welding schedules for each process: (10% of each)

OAW - 1
SMA - 23
MIG - 16
SAW - 2
TIG - 16

Total - 58

EXAMPLE ESTABLISHMENT OF BASE LINE MONITORING (Continued)

3. Distribution of monitoring to equally cover welders:

$$\frac{\text{Number of Welders Per Process}}{\text{Total Number of Welders}} \times \text{Total Monitoring}$$

OAW $\frac{2}{40} \times 58 = 2.9$

SMA $\frac{10}{40} \times 58 = 14.5$

TIG $\frac{12}{40} \times 58 = 17.4$

MIG $\frac{12}{40} \times 58 = 17.4$

SAW $\frac{4}{40} \times 58 = 5.8$

Total 58

4. Distribution of monitoring to cover shifts in proportion to number of welders:

OAW 2.9 All 1st. Shift

SMA $14.5 \times \frac{6}{10} = 8.7$ 1st. Shift

$14.5 \times \frac{2}{10} = 2.9$ 2nd. Shift

$14.5 \times \frac{2}{10} = 2.9$ 3rd. Shift

TIG $17.4 \times \frac{4}{12} = 5.8$ For Each Shift

MIG $17.4 \times \frac{4}{12} = 5.8$ For Each Shift

SAW 5.8 All 1st. Shift

EXAMPLE ESTABLISHMENT OF BASE LINE MONITORING (Continued)

5. Rounding gives:

Monitoring Per Week

Shift	OAW	SMA	TIG	MIG	SAW	Total
1	3	9	6	6	6	30
2	0	3	6	6	0	15
3	0	3	6	6	0	15
Total	3	15	18	18	6	60

6. Conclusions:

Monitoring 60 welding operations per week as distributed above gives:

- slightly more than 10% coverage of all welding operations
- more than one monitoring per week of any given welder. This may be excessive.

Final Base Line:

If this is initial establishment of base line (no prior welding), the base line of 60 monitoring events per week distributed as in the above table is a good starting point.

If welding has been in progress for some time, the reject rates would be considered. For example, consider reject rates of 1% for OAW, 12% for SMA, 2% for TIG, 8% for MIG and 4% for SAW. Assuming the company's goals are to shoot for no more than a 4% reject rate, become very concerned at at 8% reject rate and extremely concerned with a 15% reject rate, adjustments to the base line are in order. Using these reject rates, the 60 monitoring events might be readjusted to provide:

Monitoring Per Week

Shift	OAW	SMA	TIG	MIG	SAW	Total
1	1	15	2	8	4	30
2	0	5	2	8	0	15
3	0	5	2	8	0	15
Total	1	25	6	24	4	60

Analysis of Example Base Line Determination

The foregoing example of establishment of the amount of process monitoring illustrates that judgment is used. The 10% starting point is arbitrary but not unreasonable. The ratio of the number of monitoring events to the number of qualified welders is higher for OAW and SAW than for the other welding processes. A good reason for this higher ratio is not evident. This could have resulted in arbitrarily reducing the monitoring events for OAW and SAW. The redistribution of monitoring to take some attention away from the welding processes that have low reject rates and apply more attention to welding processes that have high reject rates involves judgment although statistical analysis could be accomplished for making such redistribution. (See Module 27-7)

Key features illustrated by the foregoing example and their merits are as follows; these four key features should be contained within every process monitoring program:

- All welding processes are subject to monitoring. Even when monitoring frequencies are redistributed, this key feature is retained. This provides at all times some amount of monitoring of each welding process to give potential for detecting deterioration in any process at an early stage should deterioration occur.
- All welders are subject to monitoring. This key feature is retained even when monitoring frequencies are redistributed. This provides for early monitoring of welders when they are assigned different welding operations.
- All shifts are subject to monitoring. This provides assurance that controls are working when the extra management and engineering support typically avail-

able on the day shift are not present.

- All welding stations are subject to monitoring. This provides assurance of compliance with welding controls regardless of where welding is performed.

ADMINISTRATIVE CONTROLS FOR PROCESS MONITORING

Implementation of the process monitoring program is more effective when written guidelines are employed. Due to the nature of process monitoring, these guidelines are not overly rigid. Since adjustments are frequently made in the program, the guidelines do not "spell out" all possible adjustments, but instead give responsibilities and criteria for determining and implementing the adjustments. The guideline procedure encompasses subjects to be monitored, designation of a responsible lead person, base line frequency, criteria for adjustments, check lists for each subject, provision for reporting results, and provisions for corrective action.

Guideline Procedure

Necessary administrative controls are established by the development of a single guideline procedure. This procedure is typically prepared by the Quality Assurance Department and implemented by the QA/QC Technicians assigned to the process monitoring function. It contains guidelines on seven elements as follows:

- Identification of Subjects to be Monitored - This module discusses subjects in terms of welding processes. Therefore, the subjects to be monitored are the welding processes employed. However, the process monitoring function can be applied to any activity that accomplishes the same type of task on a frequent basis. In addition to welding, potential subjects include brazing, wiring, material issue and control, cleaning, testing, maintenance, operations, housekeeping, radiation protection, security, and safety.

- Identification of Base Line Monitoring Frequencies - For each subject to be monitored, a base line frequency is established as a target frequency. It is stated in terms of monitoring events per time period, e.g., 2 per week, 4 per two weeks, etc. This permits accomplishing the monitoring at any time within the time period. It permits the QA/QC Technician to select specific times within the time period when it is known that the subject process is underway. It permits redistribution of effort when warranted.
- Assignment of Responsibilities - A lead person (normally a supervisor) is assigned total responsibility for the monitoring program. This includes responsibilities for development of check lists, direction to technicians, adjustments to base line frequencies, and assuring effective and documented results. QA/QC Technicians are assigned responsibilities for performing process monitoring. This includes responsibilities for using check lists, documenting results, issuing corrective action requests on deficiencies found, and following up to insure implementation of corrective action.
- Listing of Criteria for Adjustment of Monitoring Frequency - The frequency of in-process monitoring requires periodic assessment to insure that a representative sample of production activity is obtained and that concentrated attention is given to problem areas. To accomplish these purposes, typical cri-

teria governing the frequency of process monitoring are:

  - monitor at least between 5% and 10% of the welding operations for each welding process.
  - monitor on each shift employing welding.
  - monitor each qualified welder at least twice per month
  - increase monitoring of any welding process whose reject rate exceeds 8%.
  - provide full time monitoring of any welding process whose reject rate exceeds 15%.
- Use of Check Lists - The guideline procedure requires use of check lists as a guide to prevent overlooking key characteristics of welding operations during the monitoring function. Preparation of these check lists is discussed later in this module.
- Provisions for Reporting Results - A wide variation exists in industry practices with respect to reporting results of process monitoring because local management objectives may require little or considerable reporting. As a minimum, provision is made for recording the fact that welding operation was monitored as each monitoring activity is completed. Such record may be a log book, check-off on the monitoring schedule, or issuance of a special report. The primary purposes of this record are to provide objective evidence of the accomplishment of process monitoring and to compare accomplishments against schedule. Some companies employ additional record keeping practices to permit a trend analysis on the results. These records typically report total number of observations made, number of deficiencies found, hours expended in the monitoring activity, and a weighting factor that indicates the

relative significance of deficiencies found. These data permit trending such items as ratio of defectives to total observations, ratio of defectives to monitoring hours, and the same ratios weighted by relative significance of defectives. Regardless of the reporting method, another document (typically titled Corrective Action Request) is issued to responsible departments whenever a deficiency is found.

- Provisions for Corrective Action - Whenever the process monitoring function identifies a deficiency (e.g., failure to comply with procedures or welding codes), the department responsible for the welding operation is required to take corrective action. The process monitoring procedure typically provides for issuance of a Corrective Action Request (CAR) to the responsible department. The CAR identifies the welding operation, the deficiency, the date of discovery, the date by which correction is requested, and the preparer of the CAR. The responsible department determines action necessary to correct the specific deficiency and to prevent its recurrence. These are documented on the CAR which is then returned to the preparer. The preparer is typically responsible for following up to assure that the stated corrective actions have been taken and are effective.

Check Lists

Check lists for process monitoring can be generic in nature because welding processes employ the same type of characteristics in all applications. As long as all possible characteristics are included generically in the check list, the same check list can be used to monitor any application of any welding process. However, when certain applications of a given welding process occur infrequently and such applications have unique requirements, it is typically best to prepare separate check lists for the infrequent and unique applications. Therefore, typical process monitoring programs include a check list for each of the "general" welding, hardsurfacing, seal welding, and tube-to-tube sheet welding.

Each check list serves to remind the monitor of key features (characteristics) to be checked. To determine specific requirements governing a particular characteristic, the monitor refers to the job package at the welding site. When it is recalled that the job package has been previously reviewed for compliance with the applicable welding code, it is evident that compliance with the job package equates to compliance with the welding code.

A typical check list for general welding is given in Table 28-6-1. This check list is suitable for monitoring OAW, SMA, TIG, MIG or SAW welding processes. Items on the check list that are not relevant to a specific welding process are simple considered not applicable.

TABLE 28-6-1

GENERAL WELDING MONITORING CHECK LIST

Frequency: Established per Quality Procedure ________________.

Instructions: Each surveillance will check as many items on this check list as possible. More than one welding operation may be checked to complete all items. The applicable welding procedures shall be used as acceptance criteria. A _________ form will be issued for deficiencies noted.

Check List:

A. Administrative Checks
  1. Correct welding procedure number and revision.
  2. Welding procedure is qualified.
  3. Welder is qualified.
  4. Job package is complete.

B. Requirements Prior to Welding
  1. Correct joint design.
  2. Correct welding position.
  3. Correct fit-up and alignment (including backing or inserts as appropriate)
  4. Correct base material.
  5. Correct filler material.
  6. Cleanliness.
  7. Correct backing and flow.
  8. Correct preheat if required.
  9. Correct electrode.
  10. Record of inspection (where required)

C. Requirements During Welding
  1. Correct type and polarity of current or fuel gas for OAW
  2. Correct current and voltage
  3. Correct type and flow of shielding gas
  4. Correct techniques.
    a. Position
    b. Tack welding
    c. Bead sequence and oscillation
    d. Interpass temperature if specified
    e. Crater fill or grinding
    f. Interpass cleaning
    g. Back gouging
  5. Proper provision for root and intermediate layer inspection where required.

D. Requirements After Welding
  1. No visually discernable defects (under cut, burnthrough, excessive reinforcement, cracks, incomplete insert melting).
  2. Proper provision for post weld heat treatment.
  3. Proper provision for post weld inspection.

WELD DEFECT ANALYSIS

Weld defect analysis uses acceptance inspection results to identify troublesome welds or welding processes. The defect analysis report identifies where additional effort is needed to reduce either the number or severity of welding defects. Essential elements of the defect analysis program are data collection, analysis, reporting and corrective action.

Data Collection

Since weld defect analysis is concerned with the ability to produce acceptable welds, the acceptance inspection results serve as the raw data to be collected. Acceptance inspection methods include visual inspection, magnetic particle testing, liquid penetrant testing, ultrasonic testing, and radiographic testing. (Module 28-7 describes the purposes and uses of acceptance inspections.) For weld defect analysis, it is sufficient to understand that each of these methods will report that a weld is accepted or rejected and for each rejection, the type of welding defect is reported.

In determining which of the available data to collect, a determination is made of the potential usefulness of the weld defect analysis program. If weld defects can be repaired cheaper than the cost of a weld defect analysis program, the program would not be particularly useful. Experience has shown that defects on the surface of the weld (e.g., excessive reinforcement, undercut, uncleanliness, pits at stops, crater cracks at stops, unfilled craters at stops, etc.) are quickly repaired with relatively little cost. On the other hand, defects in the weld metal and heat affected zone are more costly to repair. For this reason, visual, magnetic particle, and liquid penetrant inspections, which detect surface defects, are typically not included in the data collection scheme. Instead, radiographic and ultrasonic testing reports serve as the raw data to be collected since these test methods detect subsurface defects.

Collection of raw data is accomplished by designating a copy of each radiographic and ultrasonic testing report to be issued to a central place for analysis. This copy is issued as soon as the report is generated (i.e., prior to any disposition of the report) to permit timely analysis. The Quality Assurance Department or the Welding Engineering Department may be the central collection agent responsible for weld defect analysis.

Dependent on the method of analysis, additional data may be collected, such as labor hours and size of defects.

Analysis

The method of analysis determines the usefulness of the results. If one were to speculate on what results might be desirable, the initial answer might be to identify the number of defective welds for each welding process. Such information would be more useful if it were also known how many total welds were made in the same time period. The ratio of these numbers gives a simple index for each welding process that indicates where the problems are in a broad sense. This simple method of analysis is illustrated in Example #1. (NOTE: Numerical values in all examples are for illustration only.)

EXAMPLE #1

WELD DEFECT ANALYSIS - SIMPLE METHOD

Method of Analysis:

$$\frac{\text{Number of defective welds per welding process}}{\text{Total number welds by that welding process}} \times 100 = \text{percent defective}$$

Examples:

OA $\frac{1}{3} = 33\%$

SMA $\frac{27}{308} = 8.8\%$

SAW $\frac{54}{84} = 64.3\%$

Examination of Example #1 reveals that the results of this simple method may be misleading. While the submerged arc welding process is apparently giving unacceptable results, it is questionable whether the same conclusion applies to oxyacetylene welding. Also, the cost of repairing the 27 SMA defective welds could exceed the cost of repairing the 54 SAW defective welds. This simple method of analysis has inherent weaknesses of wide variance in percent defective without explanation.

Weaknesses of the simple method of analysis are mostly overcome by normalizing the data with labor hours. In this method, labor hours for making the weld and predicted labor hours for repairing the weld are collected. Predicted repair labor hours are collected to avoid waiting until repairs are actually made to make the analysis. Example #2 illustrates the labor hour method of analysis.

EXAMPLE #2

WELD DEFECT ANALYSIS - LABOR HOUR METHOD

Method of Analysis:

$$\frac{\text{No. Defective}}{\text{Total No.}} \times \frac{\text{Repair Hours}}{\text{Original Hours}} \times 100 = \text{percent defective}$$

Examples:

OA $\frac{1}{3} \times \frac{0.2}{1.5} \times 100 = 4.4\%$

SMA $\frac{27}{308} \times \frac{54}{924} \times 100 = 0.5\%$

SAW $\frac{54}{84} \times \frac{160}{336} \times 100 = 30.6\%$

Examination of Example #2 reveals that the percent defective now represents both the number of defective welds and a measure of severity of the defects (expressed in the ratio of repair hours to original hours). This method identifies where largest repair costs exist and the results are, therefore, useful. A weakness lies in the ability to obtain accurate estimates of anticipated repair hours. These estimates can vary widely dependent on the experience of the persons making the estimates.

An indicator of severity of defects that does not have to be estimated can be obtained directly from acceptance inspection reports. This indicator is the size of the defect. Example #3 illustrates a defect analysis method that uses the ratio of defect length to total weld length.

EXAMPLE #3

WELD DEFECT ANALYSIS - LENGTH METHOD

Method of Analysis:

$$\frac{\text{No. Defects}}{\text{No. Welds}} \times \frac{\text{Total Defect Length}}{\text{Total Weld Length}} \times 100 = \text{Percent Defective}$$

Examples:

OA $\frac{1}{3} \times \frac{1}{9} \times 100 = 3.7\%$

SMA $\frac{27}{308} \times \frac{100}{2500} \times 100 = 0.4\%$

SAW $\frac{54}{84} \times \frac{900}{3300} \times 100 = 17.5\%$

Comparison of Example #3 with Example #2 reveals that the same relationships are retained but SAW percent defective appears less severe in Example #3. The probable reason is the failure of the length method to consider the depth of the weld defect. Defects close to the surface are repaired more quickly (and less costly) than defects deep in the weld metal. This disadvantage can be overcome by using the volume method of analysis where the volume of repair is compared to the total volume of the weld. This method is illustrated in Example #4.

EXAMPLE #4

WELD DEFECT ANALYSIS - VOLUME METHOD

Method of Analysis:

$$\frac{\text{No. of Defects}}{\text{No. of Welds}} \times \frac{\text{Repair Volume}}{\text{Total Volume}} \times 100 = \text{Percent Defective}$$

Examples:

OA $\frac{1}{3} \times \frac{0.5}{4.5} \times 100 = 3.7\%$

SMA $\frac{27}{308} \times \frac{150}{1350} \times 100 = 0.9\%$

SAW $\frac{54}{84} \times \frac{950}{2000} \times 100 = 30.5\%$

SUMMARY

Of the four methods described, the labor hour method and the volume method give the best indication of troublesome welding processes. Each uses a severity factor that is proportional to the amount of cost to repair the defects. The labor hour method has the disadvantage of being dependend on estimated repair hours. The volume method has the disadvantage of requiring considerable calculations to obtain repair and original volumes. Nonetheless, both of these methods enjoy widespread use where there are sufficient on-going welding operations to warrant a weld defect analysis program.

The simple method and the length method do not have good indicators of severity of weld defects. Nonetheless, these methods take little time to implement and are sometimes used when the number of on-going welding operations is insufficient to warrant the more complicated methods.

Weld defect analysis is typically employed by component vendors where much of the processing is by welding. It is also sometimes employed during the construction phase of a nuclear power plant. The operations phase of a nuclear power plant typically does not have sufficient welding operations to warrant weld defect analysis.

Whenever a weld defect analysis program is used, more categories than welding processes are typically analyzed. Categories are selected that will best pinpoint where the problems are occurring. For example, the percent defective may be determined for either each welding station, each shift, each procedure (or some grouping of procedures), each type of application (e.g., pipe, plate, hardsurfacing, seals, etc.), each type of defect or some combination of these.

Report of Weld Defect Analysis

The report of weld defect analysis is most effective when it is user oriented. The individual who has made the analysis has collected hoards of data which of itself is of little interest to the persons responsible for reducing the weld defect rate. Such persons are interested in where the problems are and what are the probable causes.

Weld defect analysis cannot predict with much accuracy exactly what corrective action is necessary. Instead, the analysis identifies when and where corrective action is needed. Persons responsible for improving welding performance must evaluate for what actions are necessary. These evaluations consider amount of future welding to occur, causes of the previous defects, results of recent process monitoring and a current review of welding operations.

Since the weld defect analysis report is to be user oriented, it typically reports only the analysis results.

Typical data included in reports are given in Table 28-6-2.

TABLE 28-6-2

SAMPLE WELD DEFECT ANALYSIS REPORT

Week 42

Percent Defective:

PROCESS	Stations and Shifts								
	Shop A			Shop B			Shop C		
	1	2	3	1	2	3	1	2	3
OA	2.7	N/A	N/A	0.8	N/A	N/A	1.9	N/A	N/A
SMA	12.3	6.2	5.4	3.6	7.6	7.2	6.2	6.8	6.4
TIG	2.4	1.8	2.8	0.9	1.3	1.2	2.4	1.6	2.8
MIG	N/A	N/A	N/A	9.7	12.1	11.8	5.4	6.1	5.9
SAW	N/A	N/A	N/A	4.1	3.9	3.8	2.9	3.1	3.0

Types of Defects in Percent of Total:

OA	incomplete fusion 88%, porosity 8%, others 4%
SMA	slag 74%, incomplete fusion 17%, cracks 6%, others 3%
TIG	incomplete fusion 51%, incomplete insert melting 40%, cracks 7%, others 2%
MIG	cracks 67%, burnthrough 12%, incomplete fusion 11%, porosity 8%, others 2%
SAW	burnthrough 71%, incomplete fusion 12%, slag 11%, others 6%

Instructions:

Recipients of this report are required by Procedure 1034.3 to take action as follows:

1. For percent defectives between 4% and 8%, take appropriate actions aimed toward reducing the percent defectives. These actions need not be documented.
2. For percent defectives exceeding 8%, respond to the undersigned within three days identifying corrective actions taken or planned.

(Signature)

Review of Table 28-6-2 identifies that the analyst has included types of defects as an aid to the recipients of the report in determining corrective action. For example, Shop A has a 12.3% defect rate for SMA on Shift 1. The analyis has indicated that the major cause of SMA defects is slag. Therefore, Shop A would consider interpass cleaning techniques as highly suspect.

In summary, the weld defect analysis program determines what data to collect, how to analyze the data, how to report the results, and when to take corrective actions. Either the labor hour method or the volume method gives best indication of problems. Identification of types of defects (or some other indicator of probable causes) in conjunction with percent defective permits the recipient of the report to intelligently assess the true causes of weld defects and to take effective corrective actions. In addition to periodic reports, such as that shown in Table 28-6-2, the results of each report can be graphed to show a longer term trend.

EXERCISES

The following exercises serve to reinforce the concepts covered in this module. The first three exercises refer to the MATERIALS, PROCEDURES and DATA TABLE listed in this module.

1. Obtain a copy of a company's procedures describing their welding program for monitoring of welding processes. Using this, evaluate these procedures to determine if

the key points of this module are included. (Refer to PROCEDURE Number 1 for further details.)

2. Obtain copies of actual heat treatment charts and corresponding procedural limits. Review each chart and determine if the procedural requirements were met as described in the PROCEDURES section of this module.

3. Using a copy of a company's procedure describing their weld defect analysis program and a copy of an analysis report, evaluate the procedure and the report using the information given. The PROCEDURES section of this module gives a suggestion for carrying out this exercise and a sample of welding data is included in the Data Table portion of this module.

4. The duties of the QA/QC Technician in monitoring of welding operations are performing inspections while using a check list as a guide, reporting results, issuing corrective action requests on deficiencies found and following up on implementation and effectiveness of corrective action. Briefly explain each duty.

5. Monitoring of welding operations provides an assurance that established welding program controls are in place and working. Briefly discuss how such a program can be carried out.

6. Inspections typically employed with monitoring welding operations are given in the following list. Briefly discuss each operation:
   a. Cleanliness
   b. Fit-up
   c. Welding data review

   d. Post weld heat treatment
   e. Program compliance

7. Essential elements of the Guideline Procedure for Welding Process Monitoring are given in the following list. Briefly explain each element of the guideline procedure listed.
   a. identification of subjects to be monitored
   b. identification of base line frequency
   c. assignment of responsibility
   d. listing of criteria for adjusting the monitoring frequency
   e. use of check lists
   f. provisions for reporting results
   g. provisions for corrective action

8. The welding process monitoring program should include provisions for periodically monitoring all:
   - welding procedures
   - welders
   - welding shifts
   - welding stations

   Briefly explain how this monitoring should be carried out.

9. Of four methods of weld defect analysis described by this module, the labor hour method and volume method provide the best indicators of severity of welding defects. Briefly explain.

MATERIALS

The first three suggested exercises for this module involve (1) establishment of a welding process monitoring program, (2) interpretation of heat treatment charts, and (3) performing welding defect analysis. Supplementary materials for these exercises may be desirable as follows:

1. Copy of a company's procedures describing their welding program and their program for monitoring of welding processes. Students/trainees could be requested to evaluate these procedures to determine if key points in this module are included. (To be used for Exercise #1)
2. Copies of actual heat treatment charts and corresponding procedural limits are needed for this exercise. (To be used for Exercise #2)
3. Copy of a company's procedure describing their weld defect analysis program and copy of an analysis report. Students/trainees could be requested to evaluate the procedure and report in terms of the key features described by this module. (To be used for Exercise #3)

PROCEDURES

Using the MATERIALS suggested for this module and/or the information given here, perform the following PROCEDURES in completing the first three assigned EXERCISES.

Procedure #1:

This procedure is in reference to Exercise #1 and refers to the establishment of a Welding Process Monitoring

Program.

Given: Company XYZ performs welding on an on-going basis as follows:

Shift	Welds Per Week/Number of Welders				
	OA	SMA	TIG	MIG	SAW
1	100/15	500/60	15/5	10/5	0/0
2	0/0	200/25	15/5	10/5	0/0
3	0/0	200/25	15/5	10/5	0/0

Procedure:

Establish a base line frequency for monitoring the welding processes. Document all assumptions and calculations. Determine the minimum number of technicians necessary for implementing the monitoring program. (Use 40 hour work weeks, but with daily assignments on any shift. Assume Company XYZ works only five days per week. Assume it takes 2 labor hours for each individual monitoring activity including reporting and following up on corrective action.)

Procedure #2:

This procedure is in reference to Exercise #2 and refers to the review of heat treatment charts and procedures.

Given: Various heat treatment charts and corresponding procedural requirements given by the instructor.

Procedure: Review each chart and determine if the procedural requirements were met as evidenced by the chart. For any violation, describe the specific violation and discuss any actions taken.

Procedure #3:

This procedure is in reference to Exercise #3 and refers to the Evaluation of a weld defect analysis program.

Given: The collection of welding data listed in Table 28-6-3 in the DATA TABLE section of this module.

Problem: For each welding process, calculate percent defective using simple, labor hour, length and volume methods. Graph the results of each method. State which method appears to be most representative and why. Determine what adjustment, if any, you would make to the process monitoring schedule determined in Exercise #1. Give rationale for any changes.

DATA TABLE

TABLE 28-6-2

WELDING DATA FOR EXERCISE #3

DAY	SHIFT	NO. WELDS	NO. DEFECTS	LABOR HR. RATIO	LENGTH RATIO	VOLUME RATIO
1	1	20(OA)	2	112/8	200/4	75/3
		100(SMA)	45	390/90	1500/180	800/185
		3(TIG)	0	40/0	125/0	100/0
		2(MIG)	2	32/8	600/100	450/60
1	2	40(SMA)	30	170/30	400/60	125/15
		3(TIG)	1	38/2	115/3	90/1

		2(MIG)	0	40/0	550/0	400/0
1	3	40(SMA)	10	150/50	325/40	100/40
		3(TIG)	0	40/0	115/0	85/0
		2(MIG)	1	32/8	550/20	400/25
2	1	20(OA)	3	112/8	190/3	70/2
		100(SMA)	22	420/60	1700/175	825/90
		3(TIG)	1	36/4	90/10	80/6
		2(MIG)	1	28/12	490/50	300/90
2	2	40(SMA)	15	184/16	420/20	140/10
		3(TIG)	0	40/0	120/0	90/0
		2(MIG)	1	16/24	300/200	200/300
2	3	44(SMA)	10	192/8	500/20	900/30
		4(TIG)	1	36/4	114/4	100/3
		2(MIG)	2	32/8	425/20	280/12
3	1	20(OA)	0	120/0	200/0	80/0
		100(SMA)	12	440/40	2000/135	900/110
		2(TIG)	0	40/0	85/0	60/0
		2(MIG)	1	36/4	450/10	325/8
3	2	40(SMA)	6	188/12	400/6	150/8
		3(TIG)	0	40/0	120/0	85/0
		2(MIG)	1	36/4	420/8	300/6
3	3	36(SMA)	8	180/40	425/30	825/130
		2(TIG)	1	32/8	110/30	80/20
		2(MIG)	1	28/12	400/10	250/90

REFERENCE MATERIALS

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, New York, NY

American Welding Society, Structural Welding Code, AWS D1.1, New York, NY

TEST

1. Name the primary objective of a welding process monitoring program.

2. Name four key features of the welding process monitoring program.
   a.
   b.
   c.
   d.

3. Name seven elements of the Guideline Procedure for the welding process monitoring program.
   a.
   b.
   c.
   d.
   e.
   f.
   g.

4. Describe how one generic check list can be used for monitoring any welding process.

5. Process control typically consists of procedures review, process monitoring and defect analysis. Briefly define each of these terms.

6. Weld defect analysis is warranted when the on-going amount of welding operations give good potential for overall cost savings through the ability of the analysis to reduce the defect rates. List the type of welding data that should be collected to properly carry out a weld defect analysis program.

NUCLEAR TECHNOLOGY

MODULE 28-7

ACCEPTANCE INSPECTION

COURSE 28 WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
⇨ MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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INTRODUCTION

Prior modules of this course have focused on all the controls aimed toward successfully making an acceptable weld. This module describes the inspections which determine if the completed weld is acceptable. Such inspections, of necessity, must be nondestructive in nature.

The techniques for performing nondestructive examinations are described by other courses of the Nuclear Technology Curriculum. Therefore, this module does not describe examination techniques. Instead, it describes how to determine what inspection is required for a given weld, when the inspection should be performed, and what acceptance standards apply. In this regard, the codes which govern acceptance of welds are described.

The content of this module pertains mostly to the acceptance inspection of welds as initially made during component manufacture and installation of such components at the nuclear power plant site. Inspection applied during the some 40 years of plant operation are also described. However, the inspections associated with weld repair are reserved for Module 28-9 of this course.

MODULE PREREQUISITES

All preceding modules of Course 28 shall be completed before proceeding to this module.

OBJECTIVES

Upon completion of this module, the student/trainee shall be able to:

1. Correlate given weld defects with the best method of nondestructive examination for detecting such defects.
2. Describe the general sequence of events whith result in identification of specific acceptance inspections for specific welds when the ASME Boiler and Pressure Vessel Code applies to manufacture or installation of components. Include the role of component classification and weld categorization.
3. Describe how either the Structural Welding Code, AWS D1.1, or the Reinforcing Steel Welding Code, D12.1, becomes applicable to nuclear power plant welding and name the types of welding governed by each of these codes.
4. Name the nondestructive examination method typically required by the ASME Boiler and Pressure Vessel Code for pressure boundary welds, filler welds, structural welds, and tube-to-tubesheet welds.
5. Relate the use of sequential processing instructions to the application of acceptance inspection instructions.
6. Name three conditions which dictate the point in time for performance of acceptance inspections.
7. Given descriptions or sketches of inspection results, determine the types of defects represented and compare the results with given acceptance standards to determine acceptability of the weld.

NOTES TO INSTRUCTOR / STUDENT

The Exercises and Procedures suggested by this module involve student/trainee research of codes applicable to welding. The availability of these codes in a reference library should be determined.

In the event the necessary codes are unavailable, activities should be developed which require students/ trainees to apply acceptance inspection criteria. For such activities, descriptions of weld classifications and acceptance inspection requirements and acceptance standards for each classification would be needed. Such descriptions could be prepared from the information given by this module as supplemented from experience.

SUBJECT MATTER

ACCEPTANCE INSPECTION METHODS AND CAPABILITIES

All inspection methods used to determine acceptability of product welds are nondestructive in nature. These inspections are typically categorized as visual inspection and nondestructive examinations (NDE). NDE methods used most frequently are radiography, liquid penetrant, magnetic particle, and ultrasonic testing. Other NDE methods used in unique applications are eddy current testing and gas and bubble testing. Course 26, NDE Techniques I, and Course 32, NDE Techniques II, describe the specific techniques associated with each NDE method.

The function of the weld and the capabilities of the acceptance inspection method determine the specific acceptance inspections required for a given weld. As described later in this module, governing codes and design documents prescribe the specific acceptance inspection and acceptance standards. At this point, the capabilities of each method are reviewed.

Visual inspection, liquid penetrant testing, and, for practical purposes, magnetic particle testing are capable of detecting weld defects on or open to the surface of a weld. While magnetic particle testing has the capability of detecting defects slightly below the surface, it is considered a surface inspection for practical purposes. Radiography, ultrasonic, and eddy current testing are capable of detecting subsurface defects. Radiography and eddy current will also detect certain surface defects. Eddy current testing has depth limitations such that it is typically employed for special testing of relatively thin-walled members. Other than for tubing, eddy current testing finds little use in nuclear power plant applications. Gas and bubble tests are used to determine integrity of certain welds in storage tanks. Within these general capabilities, the specific capabilities of each method, as applied to welds, are given in Table 28-7-1.

Table 28-7-1

NDE Capabilities

Type of Defect	Detectable By						
	Visual	Liquid Penetrant	Magnetic Particle	Radiography	Ultrasonic	Eddy Current (4)	Gas and Bubble
Arc Strikes	x						
Excessive reimforcement	x			x			
Excessive concavity or convexity	x			x			
Undercut	x	(1)	(1)	x			
Bead Overlap (rollover)	x	x	x	x			
Pitting	x	x	x	x		x	
Spatter	x			x			
Incomplete fusion				x	x	x	
Cracks		(2)	(2)	x	x	x	x
Porosity		(2)	(2)	x		x	
Inclusions		(2)	(2)	x	(3)	x	
Burn through	x			x	x	x	
Underbead cracking				x	x	x	

Notes:

(1) Undercut provides a poor surface for liquid penetrant and magnetic particle testing. While it is detectable by these methods, visual inspection and radiography are

relied upon to detect undercut. Undercut is repaired prior to performing any required liquid penetrant or magnetic particle testing.

(2) Cracks, porosity, and inclusion are detectable by liquid penetrant and magnetic particle testing when these defects are open to the surface.

(3) Large inclusions are detectable by ultrasonic testing.

(4) Eddy current testing is applicable to thin wall members only.

Table 28-7-1 indicates that defects detactable by visual inspection are also detectable by certain NDE methods. While this is factual, the visual inspection is expected to be accomplished and result in correction of such defects prior to performing NDE. However, if NDE detects visually discernible defects, such NDE would report them for correction.

Reliance is placed on visual inspection for the visually discernible defects because it is the better inspection method and because such defects can mask other defects detectable by NDE. For example visually discernible defects affect NDE as follows:

- excessive reinforcement causes dark areas on radiographs which can mask internal defects.
- excessive concavity on convexity causes lighter or darker areas respectively on radiographs but their size is not easily measured by radiographic techniques.
- undercut causes dark areas on radiographs which can mask internal defects.
- bead overlap causes linear magnetic particle and liquid penetrant indications which appear to be cracks. Radiography may or may not detect overlap dependent on the angle of radiation beam.
- pitting always gives magnetic particle and liquid penetrant indications; the much quicker visual

inspection is preferred. Pitting appears as dark rounded indications on radiographs which may mask internal defects or be confused with porosity or inclusions.

- spatter gives light indications on radiographs which may mask or be confused with internal defects.
- burnthrough gives irregular dark and light areas on radiographs and irregular responses to and eddy current examination which may mask internal defects. It is noted, however, that for welds whose inside surfaces are not visible, radiography is relied upon for detection of burnthrough.

CODES AND SPECIFICATIONS

For either shop or field welds, the QA/QC Technician is concerned with what NDE method is required and at what stage of welding should it be applied. Engineering activities normally have lead responsibility for specifying the NDE method and its application. In doing so, engineers must correctly apply the provisions of governing codes and specifications. The QA activity may have the responsibility to review or audit the results. The QC activity typically has lead responsibility for performing NDE.

The three principle codes are ASME Boiler and Pressure Vessel Code, AWS Structural Welding Code, and AWS Reinforcing Steel Welding Code. The application of NDE requirements of these codes is described below.

ASME Boiler and Pressure Vessel Code

The American Society of Mechanical Engineers Boiler and Pressure Vessel Code consists of eleven sections. Sections III and XI specify acceptance inspections and inservice inspections of welds respectively.

Section III of the code governs design, fabrication and testing of mechanical components for nuclear power plants. Section III applies to reactor vessels, other pressure vessels, pumps, valves, piping and storage tanks which comprise the nuclear power plant mechanical systems. The design agency for the power plant classifies the components consistent with the rules of the Boiler and Pressure Vessel Code. For each classification, there is a corresponding subsection of Section III which delineates design, fabrication, and testing requirements. Table 28-7-2 illustrates this correspondence.

Table 28-7-2

ASME Component Classifications

Component Class	Corresponding Subsection of Code
All	Section III, Subsection NA, Nuclear Power Plant components; General Requirements
Class 1 vessels, pumps, valves, piping, storage tanks	Section III, Subsection NB, Class 1 Components
Class 2 vessels, pumps, valves, piping, storage tanks	Section III, Subsection NC, Class 2 Components
Class 3 vessels, pumps, valves, piping, storage tanks	Section III, Subsection ND, Class 3 Components
Class MC, metal containment vessels	Section III, Subsection NE, Class MC Components
Class CS, core supports and component supports	Section III, Subsection NF, component supports Section III, Subsection NG, core supports

These component classes may be briefly defined in the following manner:

Class 1: These consist of vessels, pumps, valves, piping, and storage tanks which are part of the Reactor Coolant System (RCS) (for example, for a pressurized water reactor, PWR).

Class 2: These consist of all vessels pumps, valves, piping, and storage tanks which are part of the Emergency Core Cooling System (ECCS) Main Steam System (MS) and Feedwater System (FW).

Class 3: These consist of all vessels, pumps, valves, piping, and storage tanks for all other cooling water systems essential to safety of the plant (for example, the essential cooling water system and component cooling water systems would be considered here).

Class MC: Refers to the metal containment liner for the reactor containment building. This liner is supported by the reinforced concrete containment structure.

Class CS: This refers to reinforced concrete pressure vessels for a gas cooled reactor.
It also refers to the core supports and those structural members inside the reactor vessel.
It also refers to all of the component supports for those components which perform a safety function.

Section III requires the design agency to prepare a design specification for each component and for the system in which the component will be installed. Such design specifications give sufficient information to allow determination of the acceptance inspections required by the code.

As a minimum, the design specification must identify component name, classification, and type of weld joint to permit determination of acceptance inspection requirements for a given weld.

When the component name and classification is known, the applicable subsection of Section III is easily determined as illustrated previously in Table 28-7-2. Each subsection of Section III is arranged by Articles to have the same format as illustrated in Table 28-7-3.

Table 28-7-3

Subsection Format

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Protection Against Overpressure
8000	Name plates, Stamping, and Reports

As indicated in Table 28-7-3, Article 3000 of any subsection governs the component design. In most subsections, Article 3000 requires a further classification of welds as category A, B, C or D. These categories are based on location, service, material and thickness of the weld. Rules governing categorization of welds are as follows; a typical application is illustrated in Figure 28-7-1.

- Category A - Category A welds are comprised of longitudinal weld joints within main shells, chambers, transitions in diameter and nozzles; any welded joint within a sphere, formed or flat head, or side plates of a flat-sided vessel; and circumferential weld joint connecting hemispherical heads to other pressure retaining members.

- Category B - Category B welds are comprised of circumferential weld joints within main shells, chambers, nozzles, transitions in diameter and circumferential weld joints connecting heads other than hemispherical to other pressure retaining members.
- Category C - Category C welds are comprised of welded joints connecting flanges, tube sheets, or flat heads to other pressure retaining members and any weld joint connecting one side plate to another side plate of a flat sided vessel.
- Category D - Category D welds are comprised of welded joints connecting chambers, or nozzles to other pressure retaining members.

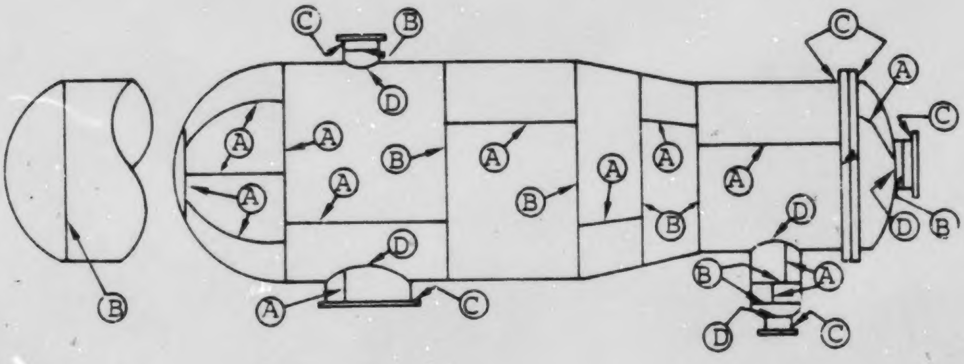

Figure 28-7-1 Typical Application of Categories A, B, C and D Welds

Article 4000 of the applicable subsection of Section III stipulates welding requirements applicable to the component manufacturer and the construction contractor at the power plant site. These requirements govern weld joint preparation, fit-up, welding, and post weld heat treatment. Article 4000 contains requirements applicable to all weld categories and unique requirements applicable to specific weld categories.

Article 5000 of the applicable subsection of Section III stipulates the acceptance inspection requirement for all combinations of types of component and categories of weld within the component. The acceptance inspection are stipulated by listing the NDE methods to be employed, the point of manufacture or construction they are to be employed, and the acceptance standards for each method.

The above discussions indicate that a series of events occur in order to properly apply the acceptance inspection requirements of Section III of the Boiler and Pressure Vessel Code. This sequence is typically as follows:

- Classification of components - The design agency includes in the system design specification the classification of each component of the system. The component classification permits determination of the applicable subsection of Section III by the manufacturer and construction contractor.
- Categorization of welds - Component welds can be categorized once the component design drawings have been prepared. Installation welds can be categorized once the system design drawings have been prepared. These design drawings identify location of welds from which welds can be categorized in accordance with Article 3000 of the applicable subsection of Section 3. Categorization of welds is normally performed by the engineering activity of the manufacturer or construction contractor. The design agency may desire to approve such categorization.

- Development of Fabrication or Installation Instructions - These instructions identify the processing steps and sequences necessary to manufacture or install the component. The engineering activity of the manufacturer or construction contractor prepare such instructions to implement the requirements of the design specification and Article 4000 of the applicable subsection of Section III. These instructions are typically termed "job package" which consists of sequential manufacturing or installation steps (e.g. traveller process routing, or job order), detail drawings, and applicable procedures such as the welding procedure specification for the job.
- Development of Acceptance Inspection Instructions - Using the component classification, the weld category, and the fabrication or installation instructions, one can locate in Article 5000 the specific acceptance inspection requirements. For a given component classification and weld category, Article 5000 lists the specific nondestructive examinations required and any requirements pertaining to the point in time where such NDE must be applied. From the manufacturing or installation instructions, the sequence matching the time dependent requires of Article 5000 can be selected. This task is accomplished by either the engineering or the QA/QC activity of the manufacturer or construction contractor. Whichever activity has lead for this task, the other activity normally has a review and concurrence function. The end result is the addition of steps for performing required NDE at the proper sequence on the manufacturing or installation listing of sequential work steps for each job.

Section XI of the ASME Boiler and Pressure Vessel Code specifies "inservice inspection" requirements for welds, pumps, and valves for the operations phase of a nuclear power plant. With regard to welds, Section XI requires classification of pressure boundary welds as class 1, 2 or 3 dependent upon the service function of the weld and its ability to be isolated from the reactor vessel. Periodic examination of these welds is required on a frequency dependent on the classification.

AWS Structural Welding Code, D1.1

The American Welding Society's Structural Welding Code, D1.1, applies to the welding of steel structures other than those components governed by the Boiler and Pressure Vessel Code. In nuclear power plant applications, the AWS Structural Welding Code typically governs welding associated with steel erection and other building construction. While the Boiler and Pressure Vessel Code governs design of components including welding design criteria, the AWS Structural Welding Code gives design criteria for welded structures only. The Architect-Engineer must determine if the AWS Structural Welding Code is pertinent to the design and whether it will be employed. Therefore, this code is applicable only when specified by the Architect-Engineer of the nuclear power plant.

The Architect-Engineer, who is the utility company or their contractor, specifies via system or component design specifications those welding operations which must meet the AWS Structural Welding Code. Where specified, the engineering and QA/QC activities of the construction contractor develop "job packages" for welding which comply with the AWS Structural Welding Code. These job packages are similar to those prepared for welding operations to the Boiler and Pressure Vessel Code. An overview of the code and its significance to engineering and QA/QC activities are given in Table 28-7-4. As indicated in the table, Section 6 of the code specifies visual inspection of welds and requires the Architect-Engineer to specify any NDE to be performed. Section 8 of the code specifies acceptance standards for welds.

AWS Reinforcing Steel Welding Code, D12.1

The American Welding Society's Reinforcing Steel Welding Code D12.1, gives requirements associated with welding of reinforcing steel in concrete structures. It is intended for use in conjunction with American Concrete Institute's Building Code Requirements for Reinforced Concrete, ACI-318. It is applicable to nuclear power plant construction only when specified by the Architect-Engineer.

Where the AWS Reinforcing Steel Welding Code is specified, the construction contractor's engineering and QA/QC activities developed "job packages" for welding of reinforcing steel which comply with the code. An overview of the code and its significance to engineering and QA/QC activities are given in Table 28-7-5. As indicated in the table, Section 7 of the code specifies visual inspection of welds and requires the Architect-Engineer to specify any NDE to be performed. Section 4 gives acceptance standards for completed welds.

Table 28-7-4

Overview of AWS Structural Welding Code

Section	Purpose	Application
1. General Provisions	Describes applicability of the code and gives general requirements which are applicable to any welding governed by the code	Architect-Engineer invokes the code consistent with its applicability; construction engineering develops welding procedures consistent with the general requirements.
2. Design of Welded Connections	Gives specific requirements governing the design of weld joints.	Construction engineering designs weld joints consistent with these specific requirements.
3. Workmanship	Gives specific requirements for the weld joint preparation, fit-up, distortion control, stress relief heat treatment, and cleaning associated with welding operations.	Construction engineering prepares welding procedures, installation drawings, and sequential listings of work steps consistent with these specific requirements.
4. Technique	Gives specific welding parameters for each welding process, including filler material, preheat and interpass temperatures shielding, positions and electrical characteristics. Also gives specific requirements pertaining to arc strikes and interpass cleaning.	Construction engineering prepares welding procedure specifications consistent with these requirements.
5. Qualification	Gives specific requirements for the qualification of welding procedures and welders.	Construction engineering establishes qualification testing of weld procedures and welders consistent with these requirements.
6. Inspection	Specifies visual inspection which are to be performed by the inspection agency designated by the project engineer. Requires the purchaser of construction work (i.e., the utility company) to specify any application of nondestructive examination (NDE). Gives requirements to be met by NDE procedures and for qualification of NDE personnel when NDE is specified.	The designated QA/QC activity performs visual inspection consistent with these requirements. When specified, the QA/QC activity prepares NDE procedures, qualifies NDE personnel, and performs NDE consistent with this section.

Table 28-7-4

Overview of AWS Structural Welding Code (Cont'd.)

7. Strengthening and Repairing Existing Structures	Gives requirements for the modification or repair by welding of existing structures	The construction or maintenance engineering activity develops modifications or repairs consistent with these requirements.
8. Design of New Buildings	Gives design criteria which must be considered with respect to welding associated with building construction. These criteria supplement sections 1 through 6 of the code. Gives acceptance standards for completed welds.	Either the design activity or the construction engineering activity design weld joints consistent with these requirements. Inspection of welds determines compliance with specified acceptance standards.
9. New Bridges	Not applicable to nuclear power plants.	Not applicable to nuclear power plants.
10. New Tubular Structures	Gives design critiera which must be considered with respect to welding associated with tubular structures. These criteria supplement section 1 through 6 of the code. Gives acceptance criteria for completed welds.	Either the design activity or the construction engineering activity design weld joints consistent with these requirements. Inspection of welds determines compliance with acceptance criteria.

Table 28-7-5

Overview of AWS Reinforcing Steel Welding Code

Section	Purpose	Application
1. General Provisions	Describes applicability of the code and gives general requirements which are applicable to any welding to the code.	Architect-Engineer invokes the code consistent with its applicability; construction engineering develops welding procedures consistent with the general requirements.
2. Permissible Stresses	States permissible stress limits for welded joints in reinforcing steel.	Construction engineering designs weld joints to meet these limits.
3. Structural Details	Gives details of weld joint type preparation, and fit-up.	Construction engineering prepares installation drawings and instructions consistent with these requirements.
4. Workmanship	Gives specific requirements for preparing weld end faces, fit-up, distortion control, and the acceptance standards for completed welds.	Construction engineering prepares installation drawings and instructions consistent with these requirements. Inspection determines compliance of completed welds with the acceptance standards.
5. Technique	Gives specific requirements for welding processes including preheat and interpass temperature, arc strikes tack welds, progression, filler material and shielding.	Construction engineering prepares welding procedures consistent with these requirements.

Table 28-7-5

Overview of AWS Reinforcing Steel Welding Code (Cont'd.)

6. Qualification	Gives specific requirements for the qualification of welding procedures and welders.	Construction engineering establishes qualification testing of procedures and welders consistent with these requirements.
7. Inspection	Specifies visual inspections which are to be performed by the inspection agency designated by the project engineer. Requires the purchaser of construction work to specify any application of NDE. Gives requirements to be met by NDE procedures and for qualification of NDE personnel when NDE is specified.	The designated QA/QC activity performs visual inspection consistent with these requirements. When specified, the QA/QC activity prepares NDE procedures, qualifies NDE personnel, and performs NDE consistent with this section.

APPLICATION OF ACCEPTANCE INSPECTIONS

The specific acceptance inspection method employed for a given weld is specified by the governing welding code and/or the design specification. Typical applications are described by this module; on-the-job QA/QC activities must refer to the applicable code and design specification to determine which acceptance inspection methods apply to a specific weld.

Examinations Required by ASME Boiler and Pressure Vessel Code

The ASME Boiler and Pressure Vessel Code bases acceptance of welds on specified nondestructive examination (NDE) methods. Section III of the code specifies the NDE requirements for manufacturing and construction. Section XI of the code specifies the NDE requirements for periodically inspecting welds during the lifetime of the plant.

As previously described by this module, NDE requirements for manufacturing and construction are found in Article 5000 of the subsection of Section III for the type and class of component associated with the welding operation. In general, Article 5000 of the various subsections specifies the time of examination, the NDE methods to be used, and the acceptance standards for each NDE method. Typical requirements for time of examination and method of NDE are as follows; the acceptance standards are described later in this module:

- time of examination - Time of examination refers to the point in the manufacturing or construction sequence at which the NDE must be performed. The code requirements are structured to ensure acceptance of welds at a point in time where later manufacturing or construction sequences would not adversely affect the integrity of the weld. Typical requirements are:
  - except for certain stipulated conditions, radiography, magnetic particle, or liquid penetrant are performed after post weld heat treatment.
  - all dissimilar metal welds are examined after post weld heat treatment.
  - magnetic particle or liquid penetrant examinations of weld surfaces which will be covered with weld metal cladding are performed prior to depositing the cladding.
- method of NDE - Specific NDE requirements are specified for each type and classification of component. Typical requirements are:
  - magnetic particle or liquid penetrant examination of weld end faces prior to welding of joints two inches or more in thickness.

- radiography of completed pressure boundary welds in vessels, pipe, pumps, valves, and certain welds in storage tanks. The category of weld typically determines if the entire weld or a portion of the weld is radiographed.
- ultrasonic examination of welds made by the electroslag welding process.
- magnetic particle or liquid penetrant examination of filter welds, structural attachment welds, seal welds, and certain welds in storage tanks.
- liquid penetrant examination of weld metal cladding, hard surfaces, and tube-to-tubesheet welds.
- visual examination of stud welds.
- gas and bubble leak tests of certain welds of atmospheric storage tanks.

The inservice inspections specified by Section XI of the code are ultrasonic, magnetic particle and liquid penetrant. Ultrasonic examination applies to all class 1 welds and many class 2 and 3 welds. The remainder are inspected by magnetic particle or liquid penetrant testing.

Examination Required by Structural Welding Code and Reinforcing Steel Welding Code

The AWS Structural Welding Code, D1.1, and Reinforcing Steel Welding Code, D12.1, specifically require visual inspection for the following:

- size, length, and location of welds
- no omission or addition of weld joints without engineering approval
- no welding defects in excess of acceptance standards

As previously described, the Architect-Engineer may specify NDE methods to be used. In general, the welds covered by AWS D1.1 and AWS D12.1 are such that either radiography

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or magnetic particle examination or both would be the only NDE specified.

Significance of Application of "Magnetic Particle or Liquid Penetrant" Examination

Design specifications and the Boiler and Pressure Vessel Code specify NDE requirements by type and classification of weld joints. The base material type is normally not a direct consideration with respect to specifying the NDE method. For this reason, when weld surface inspection is required, the specification code typically specifies "magnetic particle or liquid penetrant" examination. In such cases, most companies employ the practice of applying magnetic particle examination when the weld metal is capable of being magnetized.

Carbon steels and low alloy steels are easily magnetized. Welds made of these materials are typically examined by magnetic particle as opposed to liquid penetrant examination. High alloy steels, e.g. stainless steels, have some magnetic properties but generally not of sufficient value to permit application of magnetic particle examination. Copper and aluminum alloys and most nickel alloys are non-magnetic. Therefore, for these alloys, liquid penetrant examination is employed as opposed to magnetic particle examination.

Magnetic particle and liquid penetrant examination have essentially equal capabilities. The preference for magnetic particle examination whenever the weld metal has ample magnetic properties is based on productivity. Magnetic particle examination is substantially faster than liquid penetrant examination.

ACCEPTANCE STANDARDS

Unless otherwise specified by the design specification, the applicable acceptance standards are those specified by the code which governs the welding. Sections of the three codes described by this module which specify acceptance standards have previously been listed. In all three codes, the acceptance standards are similar. The specific limits on defect sizes or number are the principle differences among the three codes. Therefore, the acceptance standards described in the following paragraph are representative of all three codes. For on-the-job work, the specific code applicable to the welding would be used to determine acceptance standards.

Radiographic Acceptance Standards

Welds examined by radiography are considered acceptable if the radiography indicates:

- no crack, underbead crack, or incomplete fusion - Such indications appear on the radiograph as dark lines which clearly defined edges.
- no elongated indications exceeding specified lengths - Such indications represent inclusion on burnthrough. Acceptable lengths of indications are specified for various ranges of weld metal thickness. High density inclusions such as tungsten and globules of weld metal resulting from burnthrough appear on the radiograph as light, elongated shapes with edges farily well defined. Low density inclusions such as slag and areas of burnthrough where metal has fallen away appear on the radiograph as dark, elongated shapes whose edges are normally ill defined. Burnthrough is distinguishable from inclusion because both dark and light areas appear on the radiograph.

- no rounded indications in excess of specified size limits or total numbers - Rounded indications represent porosity. They appear on the radiograph as dark, rounded shapes whose edges may not be sharply defined. Indications are considered rounded if their maximum length is three or less times their width.
- no groups of aligned indications have a total length over a specified limit - Aligned indications are those elongated and rounded indications which touch a hypothetical line between the center points of the two outermost indications, and which are not spaced more than a specified distance. The concern with indications which are acceptable except for their alignment is that they probably represent a crack which was only partially detected by the NDE.

Ultrasonic Acceptance Standards

Welds inspected by ultrasonic examination are acceptable except as follows:

- discontinuities interpreted as cracks, underbead cracks, or incomplete fusion are unacceptable - The inspector determines the type of discontinuity by investigating ultrasonically the shape of the discontinuity. Discontinuities having length but essentially no width are interpreted as cracks, underbead cracks, or incomplete fusion dependent on their location.
- discontinuities are unacceptable if they exceed specified amplitudes or lengths - The amplitude of the ultrasonic response from the discontinuity which is unacceptable is normally specified as any value greater than the reference level obtained from the calibration block. Such amplitude would indicate a discontinuity of larger size than the notch or

drilled hole in the calibration block. Unacceptable lengths are specified for various ranges of weld metal thickness.

Magnetic Particle Acceptance Standards

Welds inspected by magnetic particle examination are acceptable if there are:

- no cracks - Cracks appear as linear alignment of magnetic particles.
- no rounded indications exceeding specified limits of size, number, or alignment - Limits on number of rounded indications are normally specified in terms of number per six square inches of weld surface with such areas being the most unfavorable for weld acceptance. Limits on alignment of rounded indications are normally specified in terms of the number and their spacing, e.g., four or more spaced less than 1/16 inch between any two and in alignment.

Liquid Penetrant Acceptance Standards

Welds inspected by liquid penetrant examination are acceptable if there are:

- no cracks - Cracks appear as linear bleed out of the penetrant when developer is applied.
- no rounded indications exceed specified limits of size, number, or alignment - Such limits are normally specified in the same manner as for magnetic particle acceptance standards.

Gas and Bubble Leak Testing Acceptance Standards

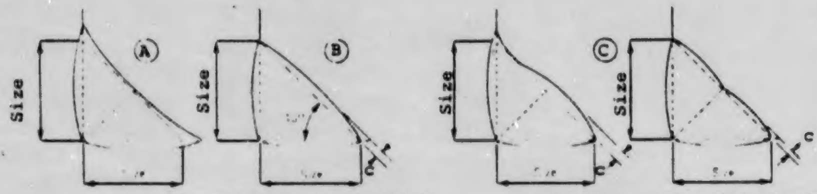
Welds examined by gas and bubble leak testing are acceptable provided there is no leaking as evidenced by formation of bubbles or the breaking of a continuous film.

Visual Inspection Acceptance Standards

Visual inspection of welds employs measuring devices, mirrors, lights, and magnification as necessary to accomplish the inspection. Welds visually inspected are acceptable provided there are:

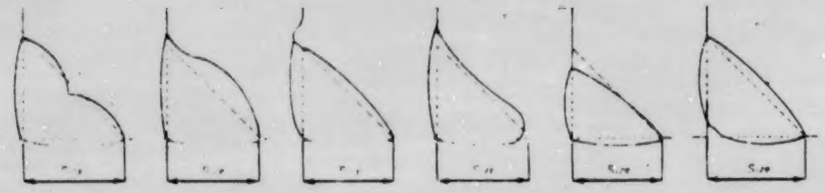
- no cracks which are visually discernable.
- no unfilled craters - Craters occur at welding stops. Craters are either filled or grounded flush with surrounding weld metal.
- no unacceptable weld profiles - This standard pertains to reinforcement, concavity, convexity, undercut, overlap, and throat thickness. Such conditions are illustrated in Figure 28-7-2 for reinforcing steel welding.

Convexity "c" shall not exceed 0.25 of size


A
B
C
Size
Size
Size
Size
Size
Size
Size
Size
c
c
c
c

Desirable Fillet Weld Profiles

Acceptable Fillet Weld Profiles


Size
Size
Size
Size
Size
Size

Insufficient Throat

Excessive Convexity

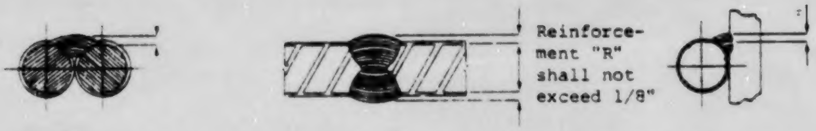
Excessive Undercut

Overlap

Insufficient Leg

Incomplete Fusion

D Unacceptable Fillet Weld Profiles



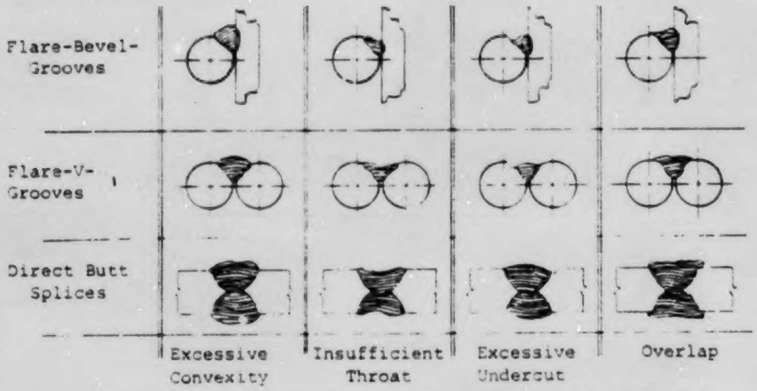
Reinforcement "R" shall not exceed 1/8"

Flare V-Grooved

Direct Butt Splice

Flare-Bevel-Groove

E Acceptable Groove Weld Profiles


Flare-Bevel-Grooves
Flare-V-Grooves
Direct Butt Splices
Excessive Convexity
Insufficient Throat
Excessive Undercut
Overlap

F Unacceptable Groove Weld Profiles

Figure 28-7-2 Weld Profile Standards for Reinforcing Steel Weldi

EXERCISES

The following exercises serve to reinforce the concepts presented in this module. The first exercise should involve an assigned weld, wherein the review of the applicable code, acceptance inspection and standards may be carried out. The remaining exercises involve questions regarding the module material.

1. Using the Procedures specified for this module, review the applicable code and extract the weld acceptance inspection requirements and corresponding acceptance standards. Locate the applicable sections, subsections and articles of the code using the guidelines presented in this module.
2. Briefly discuss how component classification and weld categorization contributes to a person's ability to extract weld acceptance inspection requirements from the ASME Boiler and Pressure Vessel Code.
3. Briefly discuss when radiography becomes applicable to welds governed by the AWS Structural Welding Code.
4. Briefly discuss or describe the following three conditions which must be met to satisfy the ASME Boiler and Pressure Vessel Code weld acceptance inspections:
    a. Following post weld heat treatment.
    b. Following post weld heat treatment for dissimilar metals.
    c. Prior to the cladding of surfaces.
5. Give examples of welds which are inspected by:
    a. Radiographic testing
    b. Liquid Penetrant testing
    c. Ultrasonic testing
6. Application of Acceptance Standards: Given the following acceptance standards, determine if the weld conditions described by question a through e are acceptable. For any unacceptable conditions, name each condition which makes the weld unacceptable.

Acceptance Standards:

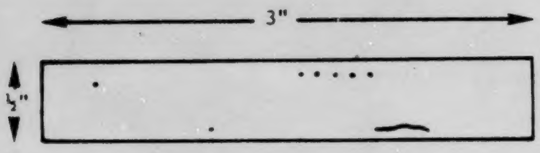
- no cracks.
- no elongated indications exceeding ¼ inch for t up to 3/4 inch, 1/3 t for t from 3/4 inch up to 2 inches, and 3/4 inch for t 2 inches and larger where t equals base material thickness.
- no rounded indications exceed ¼ t or 5/32 inch whichever is smaller where t equals base material thickness.
- no cluster of rounded indications exceeding a cluster length of 1 inch or 2 t whichever is lesser where t equals base material thickness.
- no aligned rounded indications where the sum of individual diameters exceed t in a length of 12 t where t equals base material thickness.
- all arc strikes and spatter removed and blended with surrounding surfaces.
- no undercut exceeding 1/16 inch.
- toe of weld blends smoothly with base metal with radius no smaller than ¼ inch.
- no reinforcement greater than 1/5 t or ¼ inch whichever is less where t equals base material thickness.

a. Visual inspection of a sixteen inch pipe butt joint of ½ inch wall thickness reveals bead rollover along a 1½ inch distance on one side, no discernable cracks or pits, no spatter, no arc strikes, and reinforcement equal to 3/32 inch.

b. Radiographic examination of a 5 inch pressure vessel longitudinal weld reveals two linear indications of 1 inch and 3/4 inch in length, four random rounded indications of 1/8 inch diameter, and one elongated indication of ½ inch length.

c. Radiographic examination of a six inch pipe butt joint of .250 inch wall thickness reveals a series of dark and light elongated indications ranging in size from 1/8 to 11/32 inch, a dark broad indication of ill defined edges along both sides of the weld for its entire length, one linear indication of 1/8 inch, seventeen random rounded indications of 1/16 inch diameter, and one rounded indication of 1/8 inch diameter.

d. Liquid penetrant examination of a tube-to-tubesheet weld of .125 inch thickness reveals the indications illustrated in the following sketch:



Note: All rounded indications equal 1/32 inch

e. Magnetic particle examination of a circumferential butt joint in 3 inch carbon steel shell reveals a cluster of ten rounded indications with cluster size equal to ½ inch by 7/8 inch and no other indications. The ten rounded indications are each 1/8 inch or less in diameter.

MATERIALS

The resource library should possess the following codes to permit accomplishment of the research activity suggested by this module.

- ASME Boiler and Pressure Vessel Code
  - Section III, Division 1 and 2, Nuclear Power Plant Components: General Requirements
  - Section III, Subsection NB, Class 1 Components
  - Section III, Subsection NC, Class 2 Components
  - Section III, Subsection ND, Class 3 Components
  - Section III, Subsection NE, Class MC Components
  - Section III, Subsection NF, Component Supports
  - Section III, Subsection NG, Core Support Structures
  - Section III, Appendices
- AWS Structural Welding Code, D1.1
- AWS Reinforcing Steel Welding Code, D12.1

PROCEDURES

The following is the procedure for carrying out Exercise #1.

Note to Instructor

As previously discussed in the Notes to the Instructor/Student, the student/trainee research of a code applicable to welding to determine specific acceptance inspection requirements for a given weld is suggested as an activity to reinforce the concepts presented by this module. Descriptions of welds and the applicable code for each are given below. It is suggested that each student/trainee be assigned one weld for which he or she will review the corresponding code in a reference library to determine the specific acceptance inspection requirements and corresponding acceptance standards.

Student/Trainee Procedures

1. For the assigned weld, review the applicable code and extract the weld acceptance inspection requirements and corresponding acceptance standards. Locate the applicable sections, subsections and articles of the code using the guidelines presented by this module. Use the table of contents of the code for the applicable subsection or article to locate applicable paragraphs. Part 2 of this procedure give suggested references for specific weld types.

2. Description of Welds for Research of Acceptance Inspection Requirements and Acceptance Standards
   a. ASME Boiler and Pressure Vessel Code
      (1) Longitudinal weld joint in a class 1 pressure vessel shell of 5 inch thickness.
      (2) Circumferential weld joint in a class 2 pressure vessel shell of 1½ inch thickness.
      (3) Flange to chamber connecting weld joint in a a class 2 pressure vessel of 1½ inch thickness.
      (4) Circumferential butt joint connecting class 2 pressure system piping of ½ inch wall thickness.
      (5) Sidewall joints in a class 3 storage tank of ¼ inch thickness.
      (6) Bottom joints in a class 2 storage tank of 3/8 inch thickness.
      (7) Hardsurfacing of a class 1 component.

(8) Category B partial penetration socket weld in class 2 pipe of .125 inch wall thickness.

(9) Double fillet lap joint in a class 2 component support.

b. AWS Structural Welding Code, D1.1.

(1) Fillet weld of a Tee joint in ½ inch rectangular bar stock.

(2) Double fillet lap joint in 1/8 inch rolled sheet.

c. AWS Reinforcing Steel Welding Code, D12.1

(1) V-groove butt joint in 2 inch diameter bar.

(2) Fillet weld of 1 inch diameter bar to base plate.

DATA TABLE

None.

REFERENCE MATERIALS

The American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III and Section XI, 345 East 47th Street, New York, N.Y. 10017

The American Welding Society, Structural Welding Code, D1.1, 2501 N.W. 7th Street, Miami, Fla. 33125

The American Welding Society, Reinforcing Steel Welding Code, D12.1, 2501 N.W. 7th Street, Miami, Fla. 33125.

TEST

1. Matching - Matching the best acceptance inspection method for detecting each defect by placing the symbol of the inspection method adjacent the defect.

Weld Defects

a. _____ slag inclusion in 4" weld.
b. _____ cracks open to weld surface.
c. _____ undercut.
d. _____ underbead cracks in 3" weld.
e. _____ pitting of inside surface of ½ inch tubing.
f. _____ porosity.
g. _____ incomplete fusion in 5" weld.
h. _____ spatter.
i. _____ cracking of ½" tubes installed in a heat exchanger.

Acceptance Inspection Method

VT = Visual inspection
PT = Liquid penetrant examination
MT = Magnetic particle examination
RT = Radiography
UT = Ultrasonic examination
ET - Eddy current examination

Essay - Answer the following questions. Answers should be brief and concise.

2. Describe how each of the following contributes to a person's ability to extract the weld acceptance inspection requirements from the ASME Boiler and Pressure Vessel Code:

a. component classification: ______________________________
____
____

b. weld categorization:

3. Describe how radiography becomes applicable to welds governed by AWS Structural Welding Code.

4. Describe how sequential processing steps are used in the identification of weld acceptance inspections.

5. The ASME Boiler and Pressure Vessel Code specifies three conditions which must be met with respect to the point in time where weld acceptance inspections must be applied. Name the three conditions.

6. Completion - Complete the following statements by entering the applicable acceptance inspection requirements of the Boiler and Pressure Vessel Code.

   a. Tube-to-tubesheet welds are inspected by ______________________________.
   b. Welds connecting piping in high pressure systems are inspected by ______________________________.
   c. Pressure vessel fabrication welds are inspected by __________________________.
   d. Seal welds are inspected by ______________________
   e. Class 1 welds inspected inservice are examined by ______________________________.
   f. Weld end faces of a pressure vessel nozzle weld preparation of 4.5 inches of base material thickness are inspected by ______________________________.
   g. Weld end faces of carbon steel piping of ½ inch wall thickness in a high pressure system are inspected by ______________________________.

NUCLEAR TECHNOLOGY

MODULE 28-8

FILLER METAL CONTROL

COURSE 28 WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
⇨ MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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INTRODUCTION

There are many different welding electrodes and rods which visually appear to be identical. The differences involve the specific chemistry of the metal and the ingredients of coverings and fluxes. Since each unique electrode or rod is designed for specific applications, controls are necessary to place the proper electrode or rod at each welding station. This module describes controls for accomplishing this function.

The American Welding Society has standardized the classification of electrodes and rods through the publication of specifications which govern the quality of each type of filler material. Welding codes applicable to nuclear power plants require use of these specifications for the procurement of weld filler materials. In this manner, a product of known quality is the starting point for control of weld filler material. This module describes use of the AWS specifications, control of weld filler material after receipt from the supplier, and methods of ensuring proper application of the filler material.

The Nuclear QA/QC Technician is typically responsible for assisting in the development of the procedures and practices employed for control of weld filler material. Once the procedures are in place, the QA/QC Technician is responsible for monitoring work practices for compliance with established controls.

MODULE PREREQUISITES

All previous modules in Course 28 must be completed before proceeding to this one. Also Course 15, entitled Metallargy and Metals Properties is very useful for proper understanding of this module.

OBJECTIVES

Upon completion of this module, the student/trainee shall be able to:

1. Name two methods for selecting the proper filler materials for purchase and use.
2. State the purpose of filler material specifications.
3. Define the terms classification, identification, and grouping as related to filler materials.
4. Describe the correlation of classification numbers to requirements of filler material specifications. Describe why such correlation is useful.
5. Describe the identification marking requirements for filler materials.
6. State the purpose of filler material group numbers assigned by the ASME Boiler and Pressure Vessel Code.
7. Name the five essential elements of filler material control, define each, and describe the role of each with regard to controlling filler material.
8. Describe the difference between a Certificate of Compliance and a Certified Material Test Report.
9. Describe the role of a user's control number and compare it with the role of a supplier's heat or lot number.

SELECTION AND PURCHASING OF FILLER MATERIAL

Earlier modules of this course have pointed out that welding filler materials must be compatible with the base material. That is, the resultant weld metal chemistry and mechanical properties must be similar to those of the base metal such that the weld will meet its design requirements. The engineering activity within a company normally determines the specific welding filler material to be purchased and used.

Codes governing design of nuclear components and structures give criteria for the selection of filler material. Basically, these codes ensure selection of proper filler material for use by either of two means:

- The code specifies the exact filler material to be used for welding specific base material.
- The code requires qualification of the filler material to be used.

In either case, the codes require manufacture of filler materials to standards to provide a common and known product quality for consideration in welding applications. These standards are developed by the American Welding Society (AWS) in the form of specifications which govern the quality of filler materials. Most of the AWS specifications are adopted for use in nuclear power plant applications by the American Society of Mechanical Engineers (ASME).

For welding applications governed by the ASME Boiler and Pressure Vessel Code, Section III of the Code requires use of filler material described by Section II of the Code. Section II gives applicable specifications for filler materials. These specifications are identical to AWS specifications which are required by AWS Structural Welding Code and AWS Reinforcing Steel Welding Code. Table 28-8-1 lists

Table 28-8-1

Filler Material Specifications

ASME No.	AWS No.	Title
SFA 5.1	A5.1	Mild Steel Covered Arc-Welding Electrodes
SFA 5.2	A5.2	Iron and Steel Gas Welding Rods
N/A	A5.3	Aluminum and Aluminum-Alloy Arc-Welding Electrodes
SFA 5.4	A5.4	Corrosion-Resisting and Chromium and Chromium-Nickel Steel Covered Electrodes
SFA 5.5	A5.5	Low Allow Steel Covered Arc-Welding Electrodes
SFA 5.6	A5.6	Copper and Copper Alloy Covered Electrodes
SFA 5.7	A5.7	Copper and Copper Alloy Bare Welding Rods and Electrodes
SFA 5.8	A5.8	Brazing Filler Metal
SFA 5.9	A5.9	Corrosion-Resisting Chromium and Chromium-Nickel Steel Bare and Composite Metal Cored and Standard Arc-Welding Electrodes and Rods
SFA 5.10	A5.10	Aluminum and Aluminum Alloy Welding Rods and Bare Electrodes
SFA 5.11	A5.11	Nickel and Nickel-Alloy Covered Welding Electrodes
N/A	A5.12	Tungsten-Arc Welding Electrodes
SFA 5.13	A5.13	Surfacing Welding Rods and Electrodes
SFA 5.14	A5.14	Nickel and Nickel-Alloy Bare Welding Rods and Electrodes
N/A	A5.15	Welding Rods and Covered Electrodes for Welding Cast Iron
SFA 5.16	A5.16	Titanium and Titanium-Alloy Bare Welding Rods and Electrodes
SFA 5.17	A5.17	Bare Carbon Steel Electrodes and Fluxes for Submerged Arc Welding

Table 28-8-1

Filler Material Specifications (Continued)

ASME No.	AWS No.	Title
SFA 5.18	A5.18	Mild Steel Electrodes for Gas Metal-Arc Welding
N/A	A5.19	Magnesium Alloy Welding Rods and Bare Electrodes
SFA 5.20	A5.20	Mild Steel Electrodes for Flux-Cored Arc Welding
N/A	A5.21	Composite Surfacing Welding Rods and Electrodes
SFA 5.22	A5.22	Flux Cored Corrosion-Resisting Chromium and Chromium-Nickel Steel Electrodes
SFA 5.23	A5.23	Bare Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding
SFA 5.24	A5.24	Zirconium and Zirconium Alloy Bare Welding Rods and Electrodes
SFA 5.25	A5.25	Consumables Used for Electroslag Welding of Carbon and High Strength Low Alloy Steels
SFA 5.26	A5.26	Consumables Used for Electrogas Welding of Carbon and High Strength Low Allow Steels

the AWS filler material specifications and corresponding ASME Boiler and Pressure Vessel Code identification. The purchase order for filler materials invokes the applicable specification for the specific filler material ordered.

FILLER MATERIAL CLASSIFICATION, MARKING, AND GROUPING

Definitions

The terms classification, marking and grouping have special significance to the control of filler materials. These terms are identified as follows:

- Classification is the assignment of unique alpha-numeric identifiers which are correlated by the filler material specification with specified values to be met by the filler material. Any given electrode has one, and only one, classification.
- Marking is the identification of filler material classification and lot or heat number.
- Grouping is the assimulation of classifications which are considered "like-type" for qualification purposes.

Classification Schemes

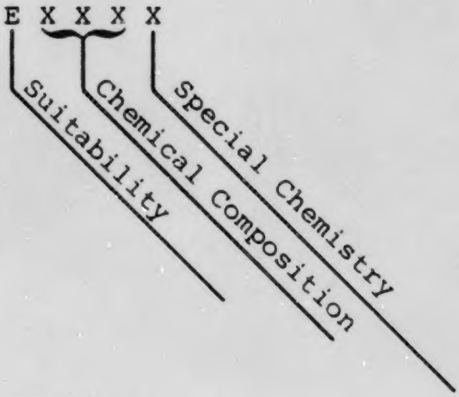
Each of the twenty-six filler material specifications listed in Table 28-8-1 gives the classification scheme for electrodes and/or rods manufactured to the specification. Within each specification, tables are given which identify the classification alpha-numeric number and the corresponding values to be met by the electrode or rod or the weld made by the electrode. Such values include requirements for chemistry, mechanical properties, coating, and flux, as applicable to the specific filler material. Since any given rod or electrode has one and only one classification, the classification defines the chemical and physical properties of the rod or electrode. Therefore, knowledge of the classification permits locating within the specification those chemical and mechanical properties which are met by the filler material.

All of the classification schemes employ "E" to signify electrode and "R" to signify rod. Electrodes are suitable as current carrying consumable electrodes. Rods are suitable as non-current carrying filler material which must be consumed by a separate flame or arc. Bare filler material which is suitable as an electrode and a rod is designated "ER".

While descriptions of all the classification schemes are too voluminous for this module, classifications for several commonly used filler materials are described.

Low alloy steel and stainless steel covered electrodes are widely used in shielded metal arc welding process. Classification of such electrodes purchased to SFA 5.4 and SFA 5.5 are illustrated as follows:

Stainless Steel Covered Electrodes, SFA 5.4, Classification



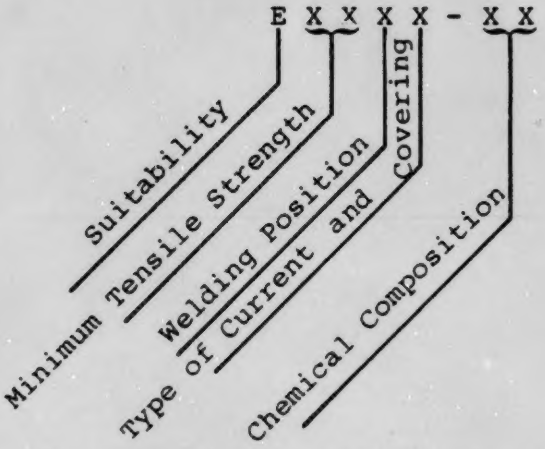
Example: E308L, Where:

E = Electrode

308 = Chemical Composition as Specified in Table 2 of SFA 5.4

L = Special Chemical Composition as Specified in Table 2 of SFA 5.4 (Low Carbon)

- Low Allow Steel Covered Electrode, SFA 5.5, Classification


E X X X X - X X
Suitability
Minimum Tensile Strength
Welding Position
Type of Current and Covering
Chemical Composition

Example: E 7010 - A1 Where:

E = Electrode

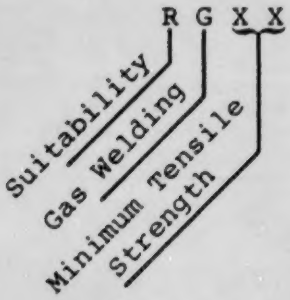
70 = 70,000 psi Minimum Tensile Strength of the Weld Deposite (Note: Units are Always in Thousands of psi. When Minimum Tensile Strength is 100,000 psi or More, a Five Digit Number is Used with the First Three Digits Representing Minimum Tensile Strength, e.g., E11018 - D2).

1 = All Welding Positions (Note: Either 1 or 2 is Used. When the Electrode is Suibtable for all Positions, it is Assigned a 1. When its Suitability is Limited to Flat and Horizontal, it is Assigned a 2).

0 = The Type of Covering and Current as Listed in Table 1 of SFA 5.5.

A1 = The Chemical Composition of the Weld Deposit as Listed in Table 2 of SFA 5.5.

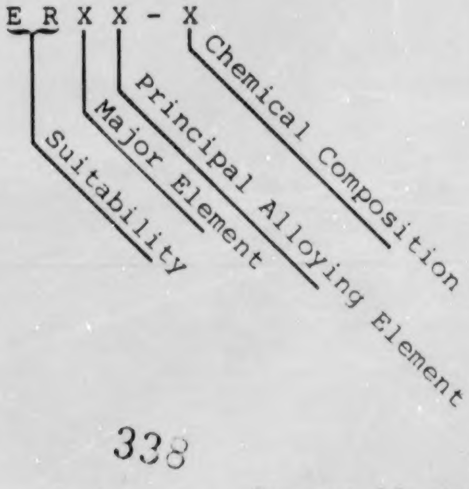
Specification SFA 5.2 describes requirements for rods used in oxyacetylene welding of carbon and low alloy steels. Classification of these "gas" rods are as follows:


R G X X
Suitability
Gas Welding
Minimum Tensile Strength

Example: RG60, Where:

R = Rod
G = Gas Welding
60 = 60,000 psi Minimum Tensile Strength

Metal inert gas and tungsten inert gas welding of nickel-base alloys with solid bare electrodes use the electrodes governed by SFA 5.14. The classification of such spooled electrodes are as follows:


E R X X - X
Suitability
Major Element
Principal Alloying Element
Chemical Composition

Example: ERNi-1

ER = Electrode and Rod

Ni - Nickel (No Principal Alloying Element)

1 - Chemical Composition per Table 1 of SFA 5.14

Example: ERNi Cr Fe - 5

ER = Electrode and Rod

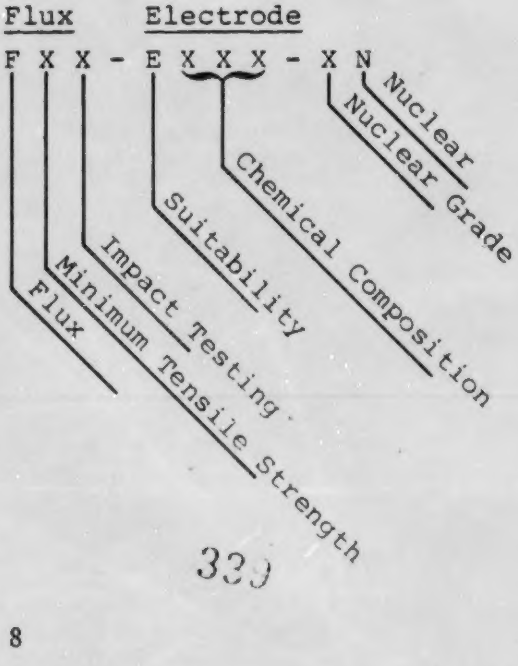
Ni = Nickel

Cr = Chromium (First Principal Alloying Element)

Fe = Iron (Second Principal Alloying Element)

5 - Chemical Composition as Specified in Table 1 of SFA 5.14

Filler materials for submerged arc welding of carbon and low alloy steels are governed by SFA 5.17. This specification classifies the flux - electrode combination as follows:


Flux
Electrode
F X X - E X X X - X N
Nuclear
Nuclear Grade
Chemical Composition
Suitability
Impact Testing
Minimum Tensile Strength
Flux

Example: F62 - EM12 - 1N, Where:

F = Flux
6 = 60,000 psi Minimum Tensile Strength of Weld Metal Deposited with this Flux-Electrode Combination
2 = Deposited Weld Metal Must Meet Impact Testing Requirements at - 20°F (Possible Other Codes are Z - No Impact Test Required, 4 - Impact Testing at - 40°F, and 6 - Impact Testing at - 60°F)
E = Electrode
M12 = Chemical Composition of the Electrode as Given by Table 1 of SFA 5.17
1 = Class 1
N = Nuclear Restriction Apply (the N is Applied for Electrodes Used in Making Welds Which Will be Exposed to Radiation. When it is Applied, the Restrictions Given by SFA 5.17 on Sulphur, Phosphorus, Copper and Vanadium Contents Must be Met. Such Elements Lower the Resistance to Material Damage by Radiation)

Marking

Each filler material specification requires specific marking and labeling which serve to identify the filler material. Such requirements apply to marking of packages and in certain instances, marking of filler material.

- Marking of Packages, Spools and Drums - Covered electrodes, straight length bare rods and electrodes, coils and electrodes, and fluxes are placed in "packages" to prepare them for shipment from the filler material supplier's plant. Such packages are typically cylindrical cans for covered electrodes, rectangular boxes for straight length bare rods, and square boxes for coils and fluxes. Continuous length bare electrode is wound on spools or drums. The packages for covered electrode, straight length bare rod electrode, coils and fluxes and the hub of spools and drums are marked as follows:

a. Classification Number
b. Filler Material Specification Number
c. Supplier's Name, Trade Designation, and Lot or Heat Number
d. Net Weight
e. Size of rods or electrodes

- Marking of Electrodes and Rods - In addition to marking of packages, spools and drums, marking is also required for covered electrodes and sometimes required for straight length electrodes and rods. All covered electrodes are marked with the classification number on the covering close to the grip end of the electrode. Where specified, straight length bare electrodes and rods are marked in either of two ways. Larger diameter straight lengths (typically 1/8 inch and larger) are marked with the classification number. Smaller diameter straight lengths are marked with a dot of color to represent the classification number. A description of the color-to-classification code employed must accompany the shipment. Also, purchasers may agree to accept "flag tag" marking of straight lengths. Flag tags are narrow adhesive strips which are marked with the classification number and are attached to one end of the rod or electrode.

Grouping

As described in Module 28-5, the type of filler material is an essential variable of a welding procedure specification. A change in the type of filler material requires requalification of the welding procedure specification. What constitutes a "type" of filler material requires definition to permit uniform application of the requalification requirments.

The AWS Structural Welding Code and Reinforcing Steel Welding Code do not group filler materials. Instead, each code stipulates those specific changes in filler material classification which require requalification. Such changes typically involve an increase in tensile strength (e.g., change from E7018 to E8018), a change in electrode diameter (does not involve classification), and a change from one filler material specification to another, (e.g., change from E70S of AWS 5.18 to E70T of AWS 5.20). Therefore, the practical grouping of filler material of these codes is first by filler material specification number and secondly by specific requirements applicable to each welding process.

The ASME Boiler and Pressure Vessel Code groups filler materials by classification number. Each group of filler materials contains such similar properties as to permit qualification of any one of the group to constitute qualification for all of the group within certain limits. Such limits involve specific changes for specific welding processes which are significant to the welding process. For example, a change from bare solid electrode to flux cored electrode for metal inert gas welding requires requalification although these two filler materials are within the same group. Except for such special, defined instances, the group number governs the requalification requirements.

The ASME Boiler and Pressure Vessel Code groups filler material by "F" numbers and "A" numbers. The "F" numbers represent those classifications of similar properties. The "A" numbers represent chemical analysis of weld deposits. The code stipulates requalification in terms of F numbers and A numbers, i.e., a change in F number or a change in A number requires requalification. Tables 28-8-2 and 28-8-3 list the F and A groupings.

ESSENTIAL ELEMENTS OF CONTROL

Each company who uses filler material is faced with establishing controls which place the proper, acceptable filler materials at each welding operation at the time it is needed for use. Since most companies who perform welding employ several welding processes and weld several types and grades of material, a number of filler material classifications must be controlled.

Control of filler materials employs the essential elements of certification, identification, segregation, traceability, and environmental protection. These essential elements are applied to each step in the handling and use of filler materials as illustrated in Figure 28-8-1.

Certification

Certification is defined as the act of attesting to the quality of the filler material. Certification always involves a statement signed by an official of the supplier which attests that the filler material supplied conforms with the applicable specification requirements. Such statements are termed Certificate of Compliance.

Table 28-8-2

F Grouping

F No.	ASME Specification No.	AWS Classification No.
	Steel and Steel Alloys	
1	SFA 5.1 & 5.5	EXX 20, EXX 24, EXX 27, EXX 28
2	SFA 5.1 & 5.5	EXX 12, EXX 13, EXX 14
3	SFA 5.1 & 5.5	EXX 10, EXX 11
4	SFA 5.1 & 5.5	EXX 15, EXX 16, EXX 18
4	SFA 5.4 Nom. Total Alloy 6% or less	EXX 15, EXX 16
4	SFA 5.4 Nom. Total Alloy more than 6%	EXX 15, EXX 16
5	SFA 5.4 Cr-Ni Electrode	EXX 15, EXX 16
6	SFA 5.2	RGXX
6	SFA 5.17	FXX-XXXX
6	SFA 5.9	ERXX
6	SFA 5.18	EXXS-X, EXXU-X
6	SFA 5.20	EXXT-X
6	SFA 5.22	EXXXT-X
6	SFA 5.23	FXX-EXXX-X, FXX-ECXXX-X, and FXX-EXXX-XN, FXX-ECXXX-XN
	Aluminum and Aluminum-Base Alloys	
21	SFA 5.10	ER 1100, ER 1260
22	SFA 5.10	ER 5554, ER 5356, ER 5556, ER 5183, ER 5654
23	SFA 5.10	ER 4043
24	SFA 5.10	R-SC 51A, R-SG 70A
	Copper and Copper-Base Alloys	
31	SFA 5.6 & 5.7	RCu, ECu
32	SFA 5.6 & 5.7	RCuSi-A, ECuSi
33	SFA 5.6 & 5.7	RCuSn-A, ECuSn-A, ECuSn-C
34	SFA 5.6 & 5.7	RCuNi, ECuNi
35	SFA 5.6 & 5.7	RBCuZn-A, RCuZn-C
36	SFA 5.6 & 5.7	ER-CuAl-Al, ER-CuAl-A2, E CuAl-A2, ER-Cu-Al-A3, E CuAl-B
37	SFA 5.6 & 5.7	E-CuNiAl, E CuMnNiAl, ERCuNiAl, ERCuMnNiA
	Nickel and Nickel-Base Alloys	
41	SFA 5.11	E Ni-1
41	SFA 5.14	E Ni-1
42	SFA 5.11	E NiCu-7
42	SFA 5.14	ER NiCu-7
43	SFA 5.11	E NiCrFe-1
43	SFA 5.11	E NiCrFe-2
43	SFA 5.11	E NiCrFe-3
43	SFA 5.11	E NiCrFe-4
43	SFA 5.11	E NiCrMo-2
43	SFA 5.11	E NiCrMo-3
43	SFA 5.14	ER NiCr-3
43	SFA 5.14	ER NiCrFe-5
43	SFA 5.14	ER NiCrFe-6
43	SFA 5.14	ER NiCrMo-2
43	SFA 5.14	ER NiCrMo-3
44	SFA 5.11	E NiMo-1
44	SFA 5.11	E NiCrMo-4
44	SFA 5.11	E NiCrMo-5
44	SFA 5.14	ER NiMo-1
44	SFA 5.14	ER NiMo-2
44	SFA 5.14	ER NiMo-7 (Alloy B-2)
44	SFA 5.14	ER NiCrMo-4
44	SFA 5.14	ER NiCrMo-5
44	SFA 5.14	ER NiCrMo-7 (Alloy C-4)
45	SFA 5.11	E NiCrMo-1
45	SFA 5.14	ER NiCrMo-1
45	SFA 5.14	ER NiFeCr-1
	Unalloyed Titanium	
51	SFA 5.16	ERTi-1, ERTi-2, ERTi-3, ERTi-4
	Zirconium and Zirconium Alloy	
61	SFA 5.24	ER Zr-1 ER Zr-2 ER Zr-3

Table 28-8-3

A Grouping

			Analysis*					
QW	A No.	Types of Weld Deposit	C %	Cr %	Mo %	Ni %	Mn %	Si %
442	1	Mild Steel	0.15				1.60	1.00
	2	Carbon-Moly	0.15	0.50	0.40–0.65		1.60	1.00
	3	Chrome (0.4 to 2%)–Moly	0.15	0.40–2.00	0.40–0.65		1.60	1.00
	4	Chrome (2 to 6%)–Moly	0.15	2.00–6.00	0.40–1.50		1.60	2.00
	5	Chrome (6 to 10.5)–Moly	0.15	6.00–10.50	0.40–1.50		1.20	2.00
	6	Chrome-Martensitic	0.15	11.00–15.00	0.70		2.00	1.00
	7	Chrome-Ferritic	0.15	11.00–30.00	1.00		1.00	3.00
	8	Chromium-Nickel	0.15	14.50–30.00	4.00	7.50–15.00	2.50	1.00
	9	Chromium-Nickel	0.30	25.00–30.00	4.00	15.00–37.00	2.50	1.00
	10	Nickel to 4%	0.15		0.55	0.80–4.00	1.70	1.00
	11	Manganese-Moly	0.17		0.25–0.75	0.85	1.25–2.25	1.00
	12	Nickel-Chrome-Moly	0.15	1.50	0.25–0.80	1.25–2.80	0.75–2.25	1.00

*Single values shown above are maximum.

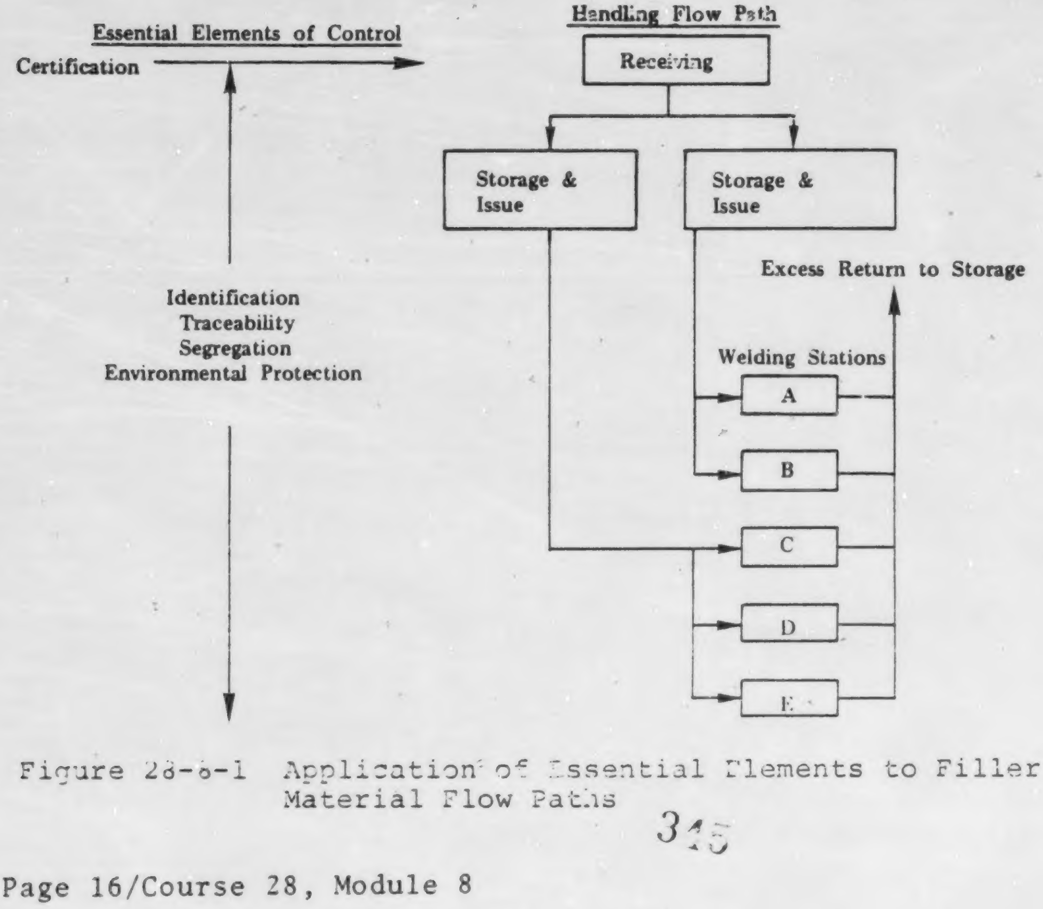

Essential Elements of Control
Certification
Identification
Traceability
Segregation
Environmental Protection
Handling Flow Path
Receiving
Storage & Issue
Storage & Issue
Excess Return to Storage
Welding Stations
A
B
C
D
E

Figure 28-8-1 Application of Essential Elements to Filler Material Flow Paths

345

In addition to Certificate of Compliance, actual results of acceptance testing performed by the supplier may be required as part of the certification. The ASME Boiler and Pressure Vessel Code requires reporting of actual test results. The AWS Structural Welding Code and AWS Reinforcing Steel Welding Code charge the design engineering activity with specifying those specific instances where actual test results must be reported. In any event, reporting of actual test results is via a Certified Material Test Report.

Certified Material Test Reports identify the results of acceptance testing required by the purchase order and by the filler material specification. These tests require the consumption of rods and electrodes and, therefore, are performed with sample rods and electrodes selected from a population having essentially identical quality. The population is defined as a lot for covered electrode and flux-cored electrode and a heat for bare rod and electrode. Lots and heats are defined as follows:

- Lot of Covered Electrodes or Flux-Cored Electrodes is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch or dry blend of flux where:
    - ____ dry batch is defined as the quantity of dry ingredients mixed at one time in one mixing vessel
    - ____ dry blend is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredient at one time in one mixing vessel

- Lot of Submerged Arc Flux is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.
- Heat of Bare Electrode, Rod or Consumable Insert is defined as the material produced from the same melt of metal.

Where required, Certified Material Test Reports are provided for each lot or heat. These reports identify the results of acceptance testing illustrated in Table 28-8-4.

Table 28-8-4

Acceptance Testing

Type of Electrode or Rod	Tests (Note 1)	Purpose of Tests
Covered Electrode	Chemistry Radiography Tensile Impact (Note 2)	Composition of Weld Soundness of Weld Strength of Weld Ductility of Weld
Straight Length Bare Rod and Electrode	Chemistry Visual (Note 2)	Composition of Rod or Electrode Soundness of Weld
Spooled Bare Electrode	Chemistry Cast and Helix Radiography (Note 2) Tensile (Note 2) Impact (Note 2) Bend (Note 2)	Composition of Electrode Electrode Freedom from Kinks and Internal Stresses Soundness of Weld Strength of Weld Ductility of Weld Ductility and Soundness of Weld

NOTES: 1. Tests are performed on either the rod/electrode or a weld made by the rod/electrode as specified.
2. These tests are required for certain classifications only.

Identification

Identification is defined as the act of (a) confirming the existence of marking and certification and (b) applying a control number. It is accomplished within the receiving inspection activity.

Confirming the existence of marking and certification is a direct function of receiving inspection. The receiving inspector compares the purchase order and material specification requirements with the marking and certification of the filler materials to conform that specified requirements have been met by the supplier.

At this point, it is important to note that the quality of weld filler materials is based on the requirements of the material specification. A logical question is whether each lot of heat of a given classification are suitable for specific applications. When considering specific applications, several variables affect the suitability of the filler material. For example, the preheat and interpass temperature limits and post weld heat treatment affect the performance of the filler material. For this reason, the ASME Boiler and Pressure Vessel Code requires specific additional tests of filler material for certain applications. Since there is some variation between lots or heats of filler material, each lot or heat must be tested. For welding applications involving AWS Structural Welding Code and AWS Reinforcing Steel Welding Code, tests in addition to those of the filler material specification are not required unless specifically requested by the design agency.

The additional tests required by the ASME Boiler and Pressure Code are summarized below. These tests are applicable for specific types of welds as identified by the Code.

- Tensile and Impact Tests - Where required, a weld metal test plate is made with each lot or heat of electrode or rod and with each welding process which will use the filler material. The weld metal test plate is subjected to the same post weld heat treatments that apply to production welds and then sectioned for testing. Such tests determine that each heat or lot will produce the strength and ductility required by the design for the specific application.

- Chemistry Tests - Where required, the chemistry of the weld metal is determined. Since the filler material specification often requires identical testing, the user may require the supplier to perform this test and report the results in the Certified Material Test Report. However, because the Code sometimes requires use of the shielding which will be used in production welding, the user must either stipulate the welding parameters to the supplier or perform this test internally. The test determines that the electrode/rod and shielding combination provides acceptable weld metal chemistry.
- Delta Ferrite Tests - Where required, weld metal deposits are analyzed for ferrite content. The user normally requires the supplier to perform this test and include the results in the Certified Material Test Report. The test is required for certain austenitic stainless steel applications where a definite amount of ferrite is described to improve resistance to cracking.

Use of a control number permits distinguishing specific lots and heats of filler material. As indicated by the foregoing discussion on additional test requirements, two lots of the same classification may be suitable for use as received or may require further testing. The specific welding application determines whether additional testing is required. Most companies establish engineering instructions to their metallurgy department for performing such additional testing and for assigning control numbers to each heat and lot of filler material. In this manner, a control number represents a known quality of the filler material. This quality represents that required by the welding code versus that required by the filler material specification.

The control number is added to the marking of packages, spools and drums when the filler material has been accepted by the additional tests or when it is known that no further testing is required. Also, the control number is placed on each test report including the supplier's certification. The filler material is now ready for storage and issue as the need arises. A listing which correlates each welding procedure specification with the control numbers of all lots or heats of filler material acceptable for use with each welding procedure specification permits issue of proper filler material to welding stations.

Segregation

Segregation is defined as the physical separation of filler materials by control number. It maintains identification of each individual package, spool or drum of filler material. Segregation prohibits comingling of filler material with different control numbers regardless of classification number. Thus, segregation guards against the inadvertant use of incorrect material. It is accomplished by procedures and work practices which include the following for all handling steps:

- Maintaining filler material in the as-supplied packages, spools, and drums wherever possible. Such containers bear the supplier's markings and the user's control number.

- Where filler material is removed from its container, providing another container marked with the correct control number.
- Requiring excess filler material to be returned from welding stations to storage in its marked container.
- Requiring scrapping of filler material for which identification has been lost.

Traceability

Traceability is defined as the ability to determine the quality of any filler material before or after its use.

Traceability is accomplished by use of the control number. At any time prior to using filler material, the practices for identification and segregation ensure that the filler material is identified by its control number at all times. At the point of use, the control number is either specified by the welding instructions or it is recorded on the weld joint record. From the control number, the corresponding metallurgical test reports and Certified Material Test Report can be retrieved.

Environmental Protection

Environmental protection is required to maintain cleanliness of filler material and, for covered electrodes and submerged arc welding fluxes, to prevent excess absorption of moisture. Either lack of cleanliness or moisture can cause weld defects.

Suppliers of filler material provide the materials in a state of cleanliness as required by the filler material specification. Regardless of the type of filler material, the supplier places it in sealed packages or bags which maintain its cleanliness.

The user of filler material maintains cleanliness by keeping the materials packaged until it is to be used at a welding station. Proper work practices by the welder ensures that cleanliness is maintained. For example, the welder does not place the filler material where it would contact excessive dirt, oil, grease, or other loose surface materials. Except for spools and drums of bare electrode which are mounted on welding machines, the filler material is consumed or returned to storage before a concern with cleanliness might arise. As long as welding machines are consuming spools or drums of bare electrode, there is no probable concern for cleanliness. However, if the machine is idle for one or more shifts, considerable dirt can collect on the exposed electrode. In such cases, dust covers are placed over the spool or drum.

Prevention of excessive moisture absorption is a more difficult matter. As long as covered electrodes and fluxes remained sealed in the supplier's packages, moisture absorption is minimal. When the seal is broken, however, moisture absorption begins at a slow rate which is dependent on temperature, humidity, and type of covering or flux. Control is established by placing the covered electrodes or fluxes in an environment which retards moisture absorption and drives out excess moisture. That is, covered electrodes and fluxes are heated prior to use.

Practical application of moisture control demands that a supply of dry electrodes and fluxes be available in quantities needed by the welders. Therefore, each storage and issue point normally has holding ovens stocked with a day's supply of covered electrodes and fluxes. The ovens are maintained at a temperature of $200^{\circ}F$ an $300^{\circ}F$. Covered electrodes and fluxes are issued from these ovens to the welding stations.

In most instances, use of the covered electrodes or fluxes within 8 hours of issue from the holding ovens ensures that insufficient moisture is absorbed to be of concern. Where electrodes or fluxes remain at a welding station for use on consecutive shifts or where it is suspected that excessive moisture is causing or may cause weld defects, portable ovens are provided to the welders for keeping the materials heated.

In the event covered electrodes or flux has been unsealed and unheated for an indeterminate time, heating them to 600°F for a few hours ensures adequate drying. If covered electrodes or fluxes are directly exposed to water, they should be scrapped.

EXERCISES

The following exercises serve to reinforce the concepts presented in this module.

1. Discuss how to determine what filler material to select for a given weld.
2. The use of a particular filler material type may cause additional test requirements for a given weld. Discuss how one may determine the additional testing requirements needed.
3. How are specific chemical and mechanical requirements for filler material specified?
4. Explain why filler materials are grouped according to "like-type" filler materials.

5. List the information which must be marked by the supplier on packages, spools and drums of filler material.
6. Briefly discuss the five essential elements for the control of filler materials.
7. Briefly explain the purpose of a Certified Material Test Report regarding material specification.
8. In reference to filler materials compare and contrast the following two terms:
    a. Classification identity
    b. Control number identity
9. Explain why it is important to physically separate filler materials according to control numbers.
10. Traceability is accomplished through application of the control number to packages, spools or drums and to each piece of paperwork relating to the corresponding heat or lot of filler material. Explain why this is important.
11. Why is environmental protection of welding rods and electrodes necessary.
12. Visit a job site where welding is being performed. Using Table 28-8-5, Control of Weld Filler Materials given in the Data Table along with the corresponding Procedure given in this module, prepare a report on the control of weld filler material using the Procedures and Data Table as a guide.

MATERIALS

None.

PROCEDURES

In reference to Exercise #12, it is suggested that the students/trainees visit a job site where welding is taking place and control of weld filler material is being carried out. Carry out the following procedure:

1. Obtain permission to visit the site.
2. Obtain any protective clothing required (hard hats, safety goggles etc.)
3. With the assistance of the job foreman or his/her designee, trace the events which occur in the receipt and use of either a lot of covered electrode filler material or a lot of spooled electrode.
4. Prepare a report on your tour which includes a description of the receipt of either of these two types of electrodes and proceed with the handling of them until their consumption in a weld.
5. In order to aid you in your report, review the Data Table (Table 28-8-5, Control of Weld Filler Materials) which gives a description which starts with receipt of these two types of electrodes and proceeds with the handling of them until their consumption in a weld. The description gives specific values for each element which are typical of those found at the job site. It is assumed that electrodes meet all inspection and test requirements.

DATA TABLE

The application of essential elements for the control of weld filler materials is described on the following pages by indicating the events which occur in the receipt and use

Table 28-8-5

Control of Weld Filler Materials

Event	Applicable To	
	Covered Electrode	Spooled Electrode
1. Receipt Inspector Confirms:		
a. Marking of Sealed Can Agrees with Purchase Order and Material Specifications: E9018-B3L, SFA 5.5, ABC Welding Products, Inc., Lowcarb 90, Lot D182, 5/32", 10 lbs.	X	
b. Spool in Sealed Plastic; Marking on Hub Agrees with Purchase Order and Material Specification: SFA 5.14, ERNiCrFe-5, Nimend, 0.035", 25 lbs., Heat 78-135		X
c. Certified Material Test Report Values Agree with Purchase Order and Material Specification Requirements	X	X
d. Receipt Inspection Paperwork Forwarded to Metallurgy Lab Who Determines:		
(1) The covered electrode requires additional testing for use in the ASME Code applications. With the assistance of engineering, weld lab, and QC, sample electrodes are withdrawn, a weld test plate is made and properly heat treated and subjected to tensile and impact tests. Afterwards, control number H-1166 is marked on all the paperwork which is filed. A release form is issued to receiving inspection which identifies E9018-B3L, Lot D182 as having control number H-1166.	X	
(2) The spooled electrode requires chemistry and delta ferrite testing of a weld deposit made with production welding procedures to be suitable for ASME Code application. The purchase order stipulated these tests including the welding parameters to be used. Results are contained in the Certified Material Test Report. Control number H-1167 is marked on all paperwork which is filed. A release form is issued to receiving inspection which identifies ERNiCrFe-5, Heat 78-135 as having control number H-1167.		X

Table 28-8-5

Control of Weld Filler Materials (Continued)

Event	Applicable To	
	Covered Electrode	Spooled Electrode
e. Receipt Inspection Marks Each of the 50 Cans of E9018-B3L, Lot D182, with the Control Number H-1166 and Each of the 25 Spools of ERNiCrFe-5, Heat 78-135 with the Control Number H-1167	X	X
f. Receipt Inspection Releases the Material to Storage	X	X
2. Storage and Issue		
a. Attendant Stores 46 Cans E9018-B3L, Lot D182, Electrodes Together on a Shelf and Opens and Places Four Cans in the Holding Oven on a Shelf Marked H-1166 (NOTE: One Can Would Have Been Opened Previously for the Additional Tests) Attendent Stores 25 Spools of ERNiCrFe-5, Heat 78-135, Together on Shelves and in Their Plastic Bags and Shipping Boxes	X	X
b. Daily, the Attendant Opens 4 Cans of E9018-B3L, Lot D182 and Places Them in the Holding Oven	X	
c. Daily, Request Forms for Filler Material are Received by Stores Which Identify the Welding Procedure Specification, the Control Number Desired and the Signature of the Welding Foreman. Requests are Honored if the Listing Issued by Metallurgy Lab Assigns the Requested Control Number to the Welding Procedure Specifications. The Attendent Notes on the Form the Weight of Electrode Issued	X	X
d. Daily, Surplus Materials are Returned. The Attendant Confirms the Materials are in Their Marked Can or Spool and Places Covered Electrodes in the Holding Oven and Spooled Electrode on Shelves	X	X
3. Welding Operations		
a. Daily, the Welding Foreman Selects "Job Packages" for Welding Schedules for that Day. The Foreman Confirms existence of Welding Procedure Specification, Fit-Up Instructions, and Inspection Instructions. The Foreman Prepares a Filler Material Request Form by Extracting the Classification and Size (e.g., E9018-B3L, 5/32")	X	X

Table 28-8-5

Control of Weld Filler Materials (Continued)

Event	Applicable To	
	Covered Electrode	Spooled Electrode
from the welding procedure specification and selecting the appropriate control number from the listing published by the Metallurgy Lab. Upon receipt of the filler material, the "job" is assigned to a welder.		
b. A QA/QC Technician is monitoring welding operations and observes SMA welding with H-1166. The technician observes that: (1) a properly executed filler material request form is in the job package. (2) electrode classification and size agree with the welding procedure specification. (3) three cans of E9018-B3L are at the station; each is marked Lot D182, H-1166. Two of the cans are in a portable warming oven and the other is next to the welder. These later electrodes are warm to the touch. (4) no other filler materials are at the welding station.	X	
c. The same QA/QC Technician then monitors MIG welding stations and observes an idle machine which has spooled electrode loaded in the machine. The technician observes that: (1) a dust cover is over the spool. (2) upon removing the dust cover, the marking on the hub bears H-1167, SFA 5.14, ERNiCrFe-5, 0.035, 25 lbs., Heat 78-135. (3) the welding foreman possesses a job package completed that shift which required use of H-1167 and contains a properly executed filler material request form. The foreman has another job package requiring use of H-1167. The foreman states that the next shift will commence the second job. (4) no other filler material is at the welding station.		X
d. The same QA/QC Technician reviews the qualification records of the welding procedure specifications which were included in the job packages for SMA and	X	X

Table 28-8-5

Control of Weld Filler Materials (Continued)

Event	Applicable To	
	Covered Electrode	Spooled Electrode
MIG welding. The SMA procedure was qualified using E9015-B3L electrode. Since the F and A numbers are the same for this electrode for E9018-B3L, the procedure is qualified. The MIG procedure was qualified using ERNiCrFe-5 electrode.		
4. Post Operations Phase In the twentieth year of operation, inservice inspection detects a small crack in a weld. A portion of the investigation of probable cause is charged with determining which filler material was used. Review of records for the cracked weld joint reveals that H-1166 (or H-1167) was used. Further review finds that this filler material was properly tested, accepted, and used. This source of potential cause is eliminated.	X (either)	X (either)

of a lot of covered electrode and a heat of spooled bare electrode.

The description starts with receipt of these two types of electrodes and proceeds with the handling of them until their consumption in a weld. The description gives specific values for each element which are typical of those found at the job site. It is assumed that electrodes meet all inspection and test requirements.

This Data Table is intended for use in carrying out Exercise #12.

REFERENCE MATERIALS

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, III and IV, New York, New York

American Welding Society, Structural Welding Code D1.1 and Reinforcing Steel Welding Code D12.1, New York, New York

TEST

1. List the two methods for selecting the proper filler materials for a given job.

2. State the purpose(s) for filler material specifications.

3. Define the following terms in reference to filler materials:
   a. Classification
   b. Identification
   c. Grouping.

4. Classification is the assignment of unique alpha-numeric identifiers which correlate with specific chemical and mechanical requirements of the filler material specificiation. Purchase orders should identify both the classification and material specification numbers. Each material specification describes its scheme for classifying rods and electrodes covered by the specification. Briefly discuss why this is useful.

5. Which of the following are essential elements for the proper control of filler materials?
   a. Certification
   b. Identification
   c. Quality
   d. Segregation
   e. Traceability
   f. Environmental protection
   g. All of the above

6. Describe the difference between a certificate of Compliance and a Certified Material Test Report.

7. Briefly describe the role of a user's control number and compare it with the role of a supplier's heat or lot number.

NUCLEAR TECHNOLOGY

MODULE 28-9

WELD REPAIR CONTROL

COURSE 28 WELDING INSPECTION

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
⇨ MODULE 28-9	Weld Repair Control
MODULE 28-10	Records

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INTRODUCTION

Considerable effort is given toward producing defect-free welds. Welding processes, procedures, and personnel are qualified and detailed instructions are prepared to guide the welder in making welds. Nonetheless, weld defects occur. When they occur, acceptable repair is assured by controls implemented by weld repair procedures and instructions.

This module describes the purposes, essential elements, and application of a weld repair control program. During study of this module, one should keep in mind that the controls described are supported by the original welding program. For example, the qualifications described by Module 28-5, the acceptance inspections described by Module 28-7, and the filler material control program described by Module 28-8 directly support the weld repair control program. Such support is assumed by this module and redundant explanations are not included.

Reports of defective welds are reviewed by the engineering department who develop or designate the weld repair procedures to be used. The Nuclear QA/QC Technician primarily monitors weld repair activities to ensure compliance with specified requirements. In this regard, the QA/QC Technician typically has responsibilities to monitor for compliance with procedures for (1) tagging defective welds, (2) removal of weld defects, (3) repair of weld defects, (4) acceptance inspection of repairs, (5) use of qualified repair procedures (6) use of qualified welders and (7) use of qualified inspection personnel.

MODULE PREREQUISITES

The student/trainee should have prior training or experience in welding qualifications and acceptance inspections of welds. Completion of the previous modules in this course are required.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. State four purposes of the weld repair control program.
2. Name five essential elements of a weld repair program and describe the role of each.
3. Describe the circumstances which permit removal of nonconforming status indication from a weld.
4. Describe how UT or RT may be employed for defect location.
5. State one advantage and one disadvantage for each of machining, grinding, and thermal gouging methods of removing weld defects.
6. State two reasons why the SMA welding process is so frequently used for repair welding.
7. Name five items which are included in engineering instructions for removing a weld defect.

SUBJECT MATTER

PURPOSES OF WELD REPAIR CONTROL

Basic Concepts

Completed welds are inspected to determine their acceptability by visual inspection and nondestructive examination. Acceptance standards are employed with each acceptance inspection method to determine if indications revealed by the inspection are acceptable. Only those indications which exceed the acceptance standards make the weld unacceptable. Therefore, an unacceptable weld is made acceptable by removing and repairing only enough indications such that the remaining indications, if any, meet the acceptance standards. Application of this concept avoids unnecessary repair and associated costs.

One can imagine the exasperation which results from repairing a weld only to find upon reexamination that the original defect is still there. That is, the portion repaired was close to, but not exactly, that position containing the defect. In welds several inches thick which contain defects somewhere within the weld volume, it is not particularly easy to accurately locate the defect. Also, when the defect is located, complete removal of the defect is necessary.

Even with successful removal of unacceptable defects, welding of the resultant cavity can introduce new defects. Such new defects can be in the repair weld metal, or it can be "damage" to adjacent areas caused by the repair process. Or, if repair welding does not introduce new defects, one must consider the effect of repair welding on the chemical and mechanical properties of the weld. In other words, are chemistry, strength, and ductility of the repair weld acceptable?

Finally, an inevitable question which arises is "how is it known that each unacceptable weld has been repaired such that all welds are now acceptable?". Construction and manufacturing activity may employ a hundred or more welders who complete tens of welds per day. When welds are found to be defective, a positive means is necessary for assuring that each defective weld is repaired.

Purposes of Weld Repair Control

From the foregoing discussion, four purposes of the weld repair program are evident. These purposes are to; (1) positively identify and accurately locate each unacceptable weld defect, (2) ensure removal of unacceptable indications prior to commencing repair welding, (3) ensure use of a qualified repair welding procedure by qualified personnel, and (4) ensure acceptance inspection of the repair weld.

ESSENTIAL ELEMENTS OF WELD REPAIR CONTROL

Five Essential Elements

A company develops written policies and procedures which assign responsibilities and duties for performing weld repair. To meet the purposes of a weld repair program, the policies and procedures cover five essential elements:

- Indication of nonconforming status of welds.
- Location and removal of defects.
- Selection and qualification of repair welding processes and personnel.
- Application of heat treatments.
- Application of acceptance inspection.

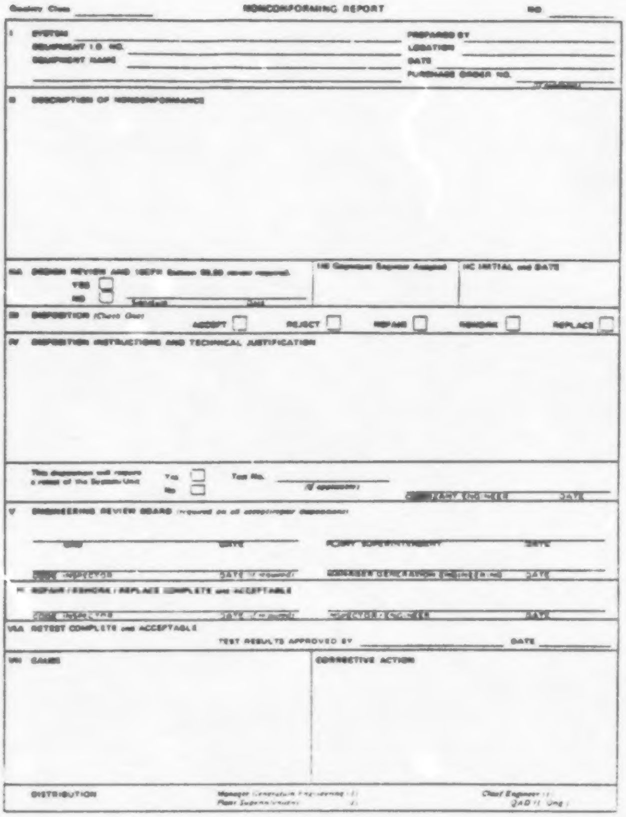
Indication of Nonconforming Status of Welds

Inspection reports are initiated whenever acceptance inspections of welds are performed. These reports identify the weld as accepted or as nonconforming dependent on the results of the inspection. When acceptance inspection determines that a weld contains defects and is, therefore, nonconforming, the inspector initiates a "nonconforming report" which describes the extent of nonconformance. This report, which is illustrated in Figure 28-9-1, is sent to engineering who determines the actions to be taken to repair or scrap the item. While actions are underway or the nonconforming report, physical identification on the weld is necessary to avoid the inadvertant use of the nonconforming weld. In other words, memory of shop personnel that the weld is nonconforming is not relied upon. Instead, a tag or label is placed on the components.

Tags or labels placed on components to indicate existence of a nonconforming condition provide for positive identification of the status of the component. As long as the tag or label is in place, it is readily apparent that the component contains a nonconforming condition. The tag or label, such as that illustrated in Figure 28-9-2, remains on the component until completion of acceptance inspection of the weld repair. When the inspection accepts the weld repair, the inspector issues an "accept" report and removes and destroys the "reject" tag or label.

Location and Removal of Defects

Nondestructive examination inspectors are normally responsible for accurately locating each defect. Surface defects are easily located. Their location is marked on the weld by the inspector, using an acceptable marking material such as no-lead paint or halogen-free ink. Subsurface defects are more difficult to locate, especially



NONCONFORMING REPORT

NO

I SYSTEM

PREPARED BY

LOCATION

DATE

PURCHASE ORDER NO.

II DESCRIPTION OF NONCONFORMANCE

III DISPOSITION

ACCEPT ☐ REJECT ☐ REPAIR ☐ REWORK ☐ REPLACE ☐

IV DISPOSITION INSTRUCTIONS AND TECHNICAL JUSTIFICATION

Yes ☐

No ☐

V ENGINEERING REVIEW BOARD

VIA RETEST COMPLETE and ACCEPTABLE

TEST RESULTS APPROVED BY ______ DATE ______

VII CAUSE

CORRECTIVE ACTION

DISTRIBUTION

Figure 28-9-1

as the thickness of the weld increases. The difficulty lies with determining the depth of weld metal at which the defect exists.

The value of time spent in locating the depth of subsurface defects is proportional to time savings in removing the defect. For relatively thin weld joints, less time is required to totally remove the weld metal in an area large enough to positively encompass the defect than the time which would be required to accurately locate the depth of the defect. However, for thicker weld joints, accurately locating the depth of the defect can save time by limiting the volume of weld metal to be removed.

Either ultrasonic examination or radiographic triangu-

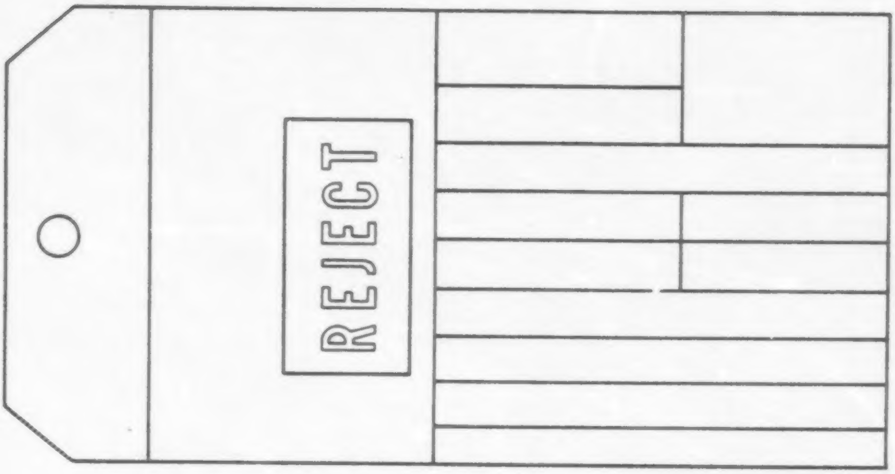
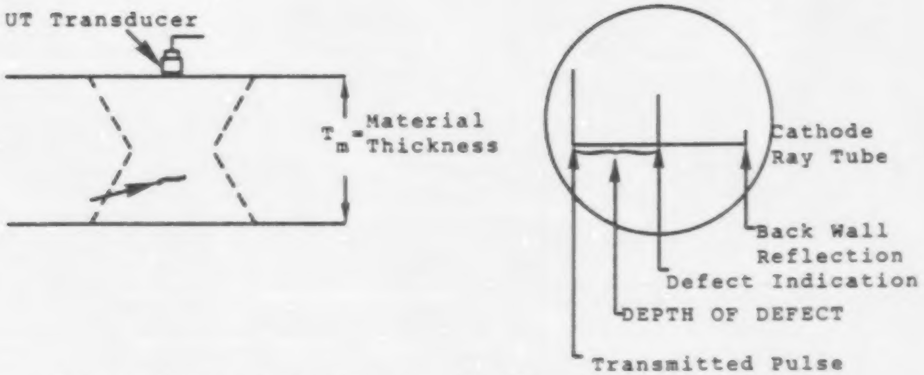


Figure 28-9-2. Sample Reject Tag

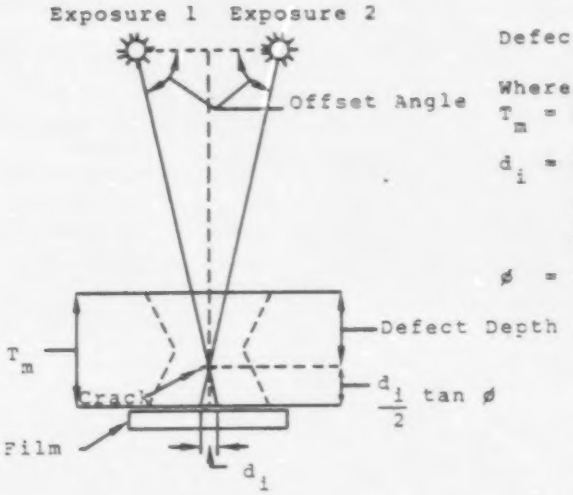
lation can accurately locate the depth of weld defects. Ultrasonic examination (UT) is the quickest of the two methods. It is used for defect depth location provided surface roughness and weld joint geometry permit application of UT. Where excess roughness or geometric forms prohibit UT, radiographic triangulation is employed. Both of these methods are illustrated in Figure 28-9-3.

In addition to marking the surface of a weld to indicate location of weld defects, the inspector prepares a sketch of the weld joint and indicates on the sketch the location and depth of the defect. This sketch serves two purposes. It assists the engineer in determining method of defect removal and it serves as a historical record of defect location.

Instructions are prepared by engineering which govern defect removal. These instructions describe the method of defect removal, the required inspection of the cavity to confirm total removal, and the required contour of the


UT Transducer
T_m = Material Thickness
Cathode Ray Tube
Back Wall Reflection
Defect Indication
DEPTH OF DEFECT
Transmitted Pulse

(a) Defect Depth Location by Ultrasonic Examination


Exposure 1
Exposure 2
Offset Angle
Defect Depth
T_m
Crack
$\frac{d_i}{2}$ tan ø
Film
d_i

Defect Depth = $T_m - \frac{d_i}{2} \tan ø$

Where:

T_m = Material Thickness

d_i = Distance Between Indications on Superimposed Film of Each Exposure

ø = Offset Angle

(b) Defect Depth Location by Radiographic Triangulation

Figure 28-9-3

Location of Defect Depth by UT and RT

cavity to confirm total removal, and the required contour of the cavity to permit repair welding. Typical methods for removing weld defects include machining, grinding, and thermal gouging.

- Machining - This method is relatively expensive and is typically used where a large volume of weld must be removed and thermal gouging is impractical. There is little likelihood of introducing new "damage" with this method.
- Grinding - This method is relatively inexpensive for removal of small to moderate volumes of weld metal. In general, grinding has a low probability of introducing new "damage". Conditions of concern for introducing damage include specialized surfaces, recesses and cavities. Some surfaces, such as seal membranes, must not be ground and cannot be weld repaired. If grinding must be performed next to these surfaces, it is best to place a barrier over the surface prior to grinding. Grinding dust which enters recesses and cavities presents a cleanliness problem and, for exposed electrical components, also presents a functional problem. Such areas are plugged or masked to prevent the entry of grinding dust.
- Thermal Gouging - This method employs flame or arc cutting. It is least expensive but has a higher risk of introducing new "damage". For thinner materials, its probability of burnthrough prohibits its use. Any time it is used, direction of the gouge and spatter of metal are sources of damage to surrounding materials. Also, its use is prohibited by welding codes for some materials. Finally, the resultant surface of the gouge may be too rough to permit inspection and some grinding may be necessary. This

method is used for removal of large volumes of metal where conditions can be controlled such that the stated concerns do not materialize. Otherwise, grinding or machining is employed.

The instructions for defect removal also include instructions for examining the repair cavity to determine if the defect has been removed. Either magnetic particle or liquid penetrant examination is performed. For very thick joints and for long cracks, close cooperation between the production and the quality control inspector can ensure defect removal with minimum metal removal. When production has removed sufficient metal to expose the defect, an inspector examines the surface to positively locate the defect. Successively, metal is removed and the surface is examined until the defect no longer exists. In any event, when production has completed removal of metal, the inspector examines the surfaces of the resulting cavity to ensure removal of the defect.

Finally, the instructions for defect removal describe the desired contour of the resultant cavity. Since the contour constitutes the weld joint preparation for repair welding, its shape can hinder or aid repair welding. In general the contour is required to have a bottom radius at least equal to the diameter of the filler material to be used by repair welding, blended side walls, and essentially a V or U shaped opening of sufficient width to afford welding access to the bottom of the cavity.

In summary, defect location and removal is accomplished by instructions prepared by engineering which delineate (1) location of defect, (2) method of removal of the defect, (3) precautions to be taken such as masking nearby recesses, (4) required inspection of the cavity surface, and (5) desired contour of the cavity.

Selection and Qualification of Repair Welding Procedures and Personnel

The repair welding procedure, the welder, and the NDE inspector are qualified to ensure the repair process is capable of producing a sound weld. Existing NDE personnel qualifications are valid for examination of repair welds. In general, the welding procedure and welder qualification for the original weld are also valid for the repair weld. However, each weld repair must be evaluated on its own merits to determine if existing welder and welding procedure qualifications are valid. This is because the essential variables associated with repair welding can be unavoidably different from the original welding procedure. If essential variables differ beyond limits, requalification of the welding procedure or welder or both is required. Most likely candidates for different essential variables are (1) use of SMA process for repair welding where TIG, MIG, or SAW was used for the original weld, (2) use of a welding position in repair welding not covered by the original qualification, and (3) change from flux-cored electrode to bare electrode or vice-versa when MIG is used for repairs.

Of the above candidates, the one most often encountered is use of SMA welding process for repair welding, regardless of the welding process used to initially make the weld. SMA is sometimes specified for repair by the welding code. It takes little time to set up, especially as compared to semiautomatic or automatic welding machines used for TIG, MIG or SAW. Also, it offers excellent control of the weld puddle in all positions. Because of these advantages of SMA for repair welding, many companies prepare and qualify SMA repair welding procedures and welders in anticipation of their need. In this manner, qualified procedures and welders are available whenever the need for weld repair arises.

Application of Heat Treatments

The heat treatment controls applicable to the original weld also apply to the repair weld. Limits for minimum preheat temperature, maximum interpass temperature, and time and temperature of post weld heat treatment are identical to those of the original welding procedure. Thus, the soundness of the repair weld is not degraded by thermal reactions. However, if the repair volume is very small as compared to the original weld volume, the technical need for post weld heat treatment is lessened. The ASME Boiler and Pressure Vessel Code recognizes instances of small repair volume where post weld heat treatment is not required. In such instances, more stringent control is placed on the repair welding process as an added precaution.

Application of Acceptance Inspection

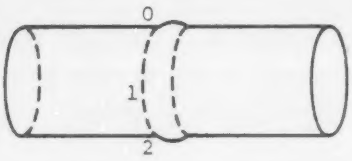
Repair welds are inspected to the same extent as the original weld. For example, if magnetic particle and radiographic examinations were required for the original weld, both of these inspections are required for the repair weld. This ensures acceptance of the repair weld to the same standard as for acceptance of the original weld.

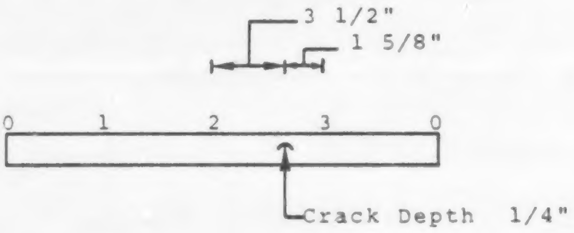
Nonetheless, there is technical basis for an exception to the above. When magnetic particle (MT) or liquid penetrant (PT) examination detects a surface defect, the repair weld is examined only by MT or PT provided the depth of the repair is shallow (within specified limits, e.g., lesser of 3/8" or 10% of weld joint thickness). For such shallow repairs, MT or PT detects the most probable repair weld defects and radiography (or ultrasonics) examination, if performed on the original weld, need not be repeated. With this single exception, repair welds are inspected to the same extent as the original welds.

Application of Essential Elements of Weld Repair Control

To illustrate the application of the essential elements of a weld repair control program, the sequential events of a weld repair are described below. Responsibilities and duties for these events are delineated by a company's procedures for weld repair.

- Magnetic particle examination of a low alloy steel welded joint in 6" diameter schedule 80 piping reveals no indications and accepts the weld.
- Radiography of the same joint reveals a crack on one of the four exposures taken to cover the entire weld. The inspector prepares a Nonconformance Report and attaches to it the radiographic inspection report and the following sketch:





- The Nonconformance Report is sent to Engineering for disposition. As completed by the inspector, this report identifies (1) the weld joint, (2) type of defect (crack), and (3) location of defect (in the 2-3 zone as identified by the sketch and supported by exposure 2-3)
- The inspector places a Nonconforming Label on the weld joint which identifies the serial number of the Nonconformance Report.
- Engineering recognizes that weld repair is necessary

and enters repair instructions on the Nonconformance Report. The instructions state repair per procedure WR-3 and MT and RT the completed repair per procedures MT-1 and RT-12. These procedures are all qualified. WR-3 requires (1) grinding to remove weld defects, (2) MT of cavity, (3) SMA repair welding, and (4) no post weld heat treatment because the original weld did not require post weld heat treatment.

- Quality engineering reviews the engineer's instructions and concurs with them.
- The Nonconformance Report is sent to the welding department, which assigns the repair work to a grinder and a welder. The grinder locates the zone markings placed on the weld joint by the radiographer and marks the spot in the 2-3 zone indicated by the sketch. In accordance with WR-3, the grinder removes weld metal at this area to a depth of 5/16" and requests an MT inspector to inspect the cavity. MT per MT-1 reveals a linear indication on one side wall of the cavity near the bottom of the cavity. The grinder removes more metal from that sidewall. The MT inspector examines the cavity, finds no indication, and enters the accomplishment of MT of the cavity per MT-1 on the Nonconformance Report. The welder repair welds in accordance with WR-3 and requests MT inspection. The MT inspector examines the repair weld per MT-1 on the Nonconformance Report.
- The Nonconformance Report is sent to the radiography group. The assigned radiographer radiographs the 2-3 zone per RT-12. The radiographic inspector finds the repair meets acceptance standards, enters accomplishment of RT per RT-12 on the Nonconformance

Report, and removes the Nonconforming Label from the weld joint. It is noted that had MT or RT found defects in the repair weld, another Nonconformance Report would have been issued and the entire cycle repeated.

EXERCISES

The following exercises reinforce the information presented in this module:

1. Obtain:
   a. Sample nonconformance report form
   b. Sample reject tag
   c. Sample weld repair control procedure

   from a local company. Following the PROCEDURES listed in this module, discuss the purposes of a weld repair control program and how the nonconforming status of welds is positively identified until such time that weld repair has been accepted.

The remaining exercises may be answered based upon the material presented in this module. An answer key is also provided for these exercises in this section of the module.

2. Read the status of a completed weld as described by each of the following items. For each, assume that all original procedures are qualified and that SMA welding is used for any necessary repair welding. Based on the content of this module, complete the statements following each description.

a. A six inch nozzle weld is made by MIG welding in a pressure vessel and subsequently stress relieved. MT and RT of the weld is required. MT is acceptable but RT finds cracks at 30° and 190° from the reference RT starting point and rejects the weld.

(1) The cracks are open to the surface.
___True ___False

(2) The inspector uses UT to determine depth of each crack. This effort is probably worthwhile. ___Yes ___No Why? (Explain)
____.

(3) The repair welding procedure required qualification because ______________________________
____.

(4) Removal of the defects is confirmed by _____ inspection.

(5) Upon completion of the weld repairs, heat treatment is required. ___Yes ___No

(6) Acceptance inspection of the weld repairs consists of _________________________________
____.

b. Baffles are SMA welded into the internals of a steam generator in close proximity to each other. Each weld is a ½-inch double bevel, fillet reinforced weld, which requires MT of both sides. All welds are acceptable except one, which has a crack on both sides for 80% of the length of the weld.

(1) Weld repair is required. ___Yes ___No.

(2) The best method of removing weld metal is grinding, because ___________________________
____.

(3) Incremental grinding and MT examination proceeds until _________________________________
____.

(4) The repair welding procedure requires qualification. ___Yes ___No.

(5) The completed repair weld is accepted by _______________ inspection.

c. Liquid penetrant examination of weld deposited stainless steel cladding by SAW reveals five rounded indications in alignment of which three are 1/8", one is 3/16", and one is 1/4"; and two 1/4" rounded indications and five 1/16" rounded indications are randomly disposed. Acceptance standards are as follows:

- Indications 1/16" and smaller are considered irrelevant.
- No cracks.
- Maximum acceptable indication size is 3/16".

(1) The indications which must be removed and repaired are ________________________________
____.

(2) Assuming that very shallow grinding removes the unacceptable indications such that weld repair is unnecessary, acceptance inspection is not required. ___True ___False.

d. Four inch carbon steel plate is prepared to form a double V butt joint. Prior to initial MIG welding, MT of the weld end faces is required. The MT reveals an unacceptable lamination on one weld end face, which requires SMA weld repair for the depth of the lamination or one inch into the base metal, whichever is less.

(1) When the lamination is ground, who is responsible for confirming defect removal?
___Grinder ___Inspector

(2) The repair welding procedure must be qualified. ___Yes ___No.

(3) Upon completion of repair welding, the MIG welding cannot yet commence because ________

____.

3. Check your answers to the exercise questions against this Answer Key. Review the text in areas where incorrect answers are noted.

a. (1) False (Because the original MT did not detect cracks.)

(2) Yes (Because of the thickness of the weld joint. Locating defect depth minimizes the amount of weld metal to be removed.)

(3) The repair welding process (SMA) differs from the original welding process (MIG).

(4) Magnetic particle.

(5) Yes (Because post weld heat treatment was required of the original weld.)

(6) Magnetic particle and radiography. (same as the original weld.)

b. (1) Yes (Cracks of this size can safely be assumed to never be acceptable.)

(2) Machining of internals is probably impossible, and thermal gouging has a high risk of gouging and spattering other baffles in close proximity.

(3) There is no longer indication of the crack. (Even if all weld metal must be removed.)

(4) No (Because it is the same as the original procedure.)

(5) Magnetic particle. (Same as for original weld.)

c. (1) The three 1/4 inch rounded indications. (After their removal, remaining indications are acceptable.)

    (2) False (Acceptance inspection is always required. In this instance, PT is confirm removal of the unacceptable indications also constitutes acceptance inspection.)

d. (1) Inspector (The act is one of confirmation which is an inspection function.)

    (2) Yes (Differs from MIG.)

    (3) The repair weld must first be determined to be acceptable by MT examination.

MATERIALS

The following materials are required to support this module:

1. Sample nonconformance report form (optional)
2. Sample reject tag (optional)
3. Sample weld repair control procedure from local company (optional).

PROCEDURES

1. In reference to Exercise #1, visit a local company and obtain the MATERIALS designated for this module.
2. The purposes of a weld repair control program are to:
    a. Positively identify and accurately locate each unacceptable weld defect.
    b. Ensure removal of unacceptable indications prior to commencing repair welding.

c. Ensure use of a qualified repair welding procedure by qualified personnel.
d. Ensure acceptance inspection of the repair weld.

Therefore, from the information you have gathered from a local company along with any discussion with on-the-job personnel discuss whether the company's weld repair control program is consistent with the purpose outlined above.

3. The five essential elements of a weld repair control program are:
    a. Indication of nonconforming status of welds.
    b. Location and removal of defects.
    c. Selection and qualification of repair welding processes/personnel.
    d. Application of heat treatments.
    e. Application of acceptance inspection.

From the information you have gathered, explain if the weld control program you have observed contains the five essential elements listed above.

4. NDE personnel identify location of defects by preparing sketches of the weld joint and relative position of defects in the weld. RT or UT may be used to assist in determining the depth of a defect.

Explain the techniques employed in determining the location and depth of the defects at the company you have visited.

5. Removal of defects may be accomplished by machining, grinding, or thermal gouging. Each method has its advantages and disadvantages.

Describe the method(s) used in preparing the nonconforming weld for repair to the same standard as the original welds at the company you have visited.

DATA TABLE

None.

REFERENCE MATERIALS

ASME, Boiler & Pressure Vessel Code, Section III, American Society of Mechanical Engineers, 3 - New York, N.Y., 1978

AWS, Structural Steel Welding Code, American Welding Society, Miami, Florida, 1976

J.M. Juran, Quality Control Handbook, McGraw-Hill, 1974

ANSI, N45.2, Quality Assurance Program Requirements for Nuclear Power Plants, The American Society of Mechanical Engineers, New York, N.Y., 1971

TEST

1. State four purposes of the weld repair control program.

2. The five essential elements of a weld repair control program are:
   a. Indication of nonconforming status of welds.
   b. Location and removal of defects.
   c. Selection and qualification of repair welding processes/personnel.
   d. Application of heat treatments.
   e. Application of acceptance inspection.

Briefly discuss how each of these five (5) elements is actually carried out in a weld repair control program.

3. Briefly discuss the circumstances which permit removal of nonconforming status indication from a weld.

4. Describe briefly how radiographic testing or ultrasonic testing may be used in locating weld defects.

5. State one advantage and one disadvantage for each of machining, grinding, and thermal gouging methods of removing weld defects.

6. State two reasons why the SMA welding process is so frequently used for repair welding.

7. Name five items which are included in engineering instructions for removing a weld defect.

NUCLEAR TECHNOLOGY

MODULE 28-10

RECORDS

COURSE 28 WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 28 WELDING INSPECTION

MODULE 28-1	Welding Fundamentals and Processes
MODULE 28-2	Shielded Metal Arc and Oxyacetylene Welding
MODULE 28-3	Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding
MODULE 28-4	Weld Joint Verification
MODULE 28-5	Qualifications
MODULE 28-6	Process Controls
MODULE 28-7	Acceptance Inspection
MODULE 28-8	Filler Metal Control
MODULE 28-9	Weld Repair Control
⇨ MODULE 28-10	Records

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INTRODUCTION

Records have an important role in all facets of industry. While records are sometimes viewed as a "necessary evil", certain records are essential and beneficial. In general, records serve three important functions:

- Specification of Agreements
- Initiation of Action in Fulfillment of Agreement
- Historical Evidence of Action Taken

These three basic roles of records are easily illustrated by a personal checking account with a financial institution. When a person opens a checking account, he or she must sign a statement of understanding of the rules governing such account. This record specifies the agreements made by the person and the institution. When the person issues a check against the account, the check itself initiates all action in fulfillment of the agreements. At each step, the action party adds an entry on the check until the person's account is docked the amount of the check which completes all agreements. Both the check and the periodic statement of account transactions give historical evidence of actions taken.

If one imagines what transpires at each step it is not difficult to recognize that a number of additional records are generated because of the check. The payee probably recorded receipt and subsequent deposits of the funds. Each involved financial institution recorded receipt and transfer of the funds in accordance with inter-banking agreements. Finally, the institution holding the account not only recorded receipt and transfer but also issued a periodic statement. If these additional records are viewed from the perspective of the organization which generated them, the same three basic roles are served.

But aren't there other records? For example, did the payer make entries on the check stub or chronological listing of issued checks? Is the value of this record merely convenience or is it necessary to properly manage the function of issuing checks? Both the value and the necessity of such "fringe" records are best judged in terms of whether they directly support one of the three basic functions of records without unnecessary duplication.

This module describes records associated with welding which fulfill the three basic roles of records. Because the most stringent requirements for welding records are stipulated by the ASME Boiler and Pressure Vessel Code, this module describes records associated with welding governed by this code. Other welding codes require similar records but not necessarily to the same extent.

MODULE PREREQUISITES

The student/trainee shall have completed all previous modules in Course 28.

OBJECTIVES

Upon completion of this module, the student/trainee shall be able to do the following:

1. Name two types of documents which describe the welding records to be maintained by any company performing welding.

2. Differentiate the purposes of documents, procedures and record forms.
3. Name three characteristics of records which represent record quality and discuss each in terms of factors which contribute to record quality.
4. Given any of the following records, state its purpose and describe how it is identifiable:
    a. Procedure Qualification Records
    b. Welder and Welding Operator Performance Qualification Record
    c. Nondestructive Examination Procedure Demonstration Record
    d. Nondestructive Examination Personnel Certification Record
    e. Certified Material Test Report
    f. Weld Joint Record
    g. Nondestructive Examination Report
5. Given any of the records listed in #4 above, state two tasks which may be assigned to the Nuclear QA/QC Technician with respect to the record.
6. Name the records associated with welding which are forwarded with data reports to the owner of the nuclear power plant.

REQUIRED WELDING RECORDS

Sources Which Require Welding Records

The initial source of requirements for welding records applicable to nuclear power plant activities in the U.S. Code of Federal Regulations (CFR). The U.S. Nuclear Regulatory Commission (NRC) issues regulations within Title 10 of the CFR. NRC has promulgated, via Appendix B to 10 CFR Part 50, eighteen quality assurance criteria to be met in the design, manufacture, installation, test and operation of a nuclear power plant. A company's Quality Assurance Manual must satisfy these criteria. The criterion on records applies to all quality assurance records, including welding records. This criterion is quoted below:

> XVII. Quality Assurance Records
>
> *Sufficient records shall be maintained to furnish evidence of activities affecting quality. The records shall include at least the following: operating logs and the result of reviews, inspections, tests, audits, monitoring of work performance, and materials analyses. The records shall also include closely-related data such as qualifications personnel, procedures, and equipment. Inspection and test records shall, as a minimum, identify the inspector or data recorder, the type of observation, the results, the acceptability, and the action taken in connection with any deficiencies noted. Records shall be identified and retrievable. Consistent with applicable regulatory requirements, the applicant shall establish requirements concerning record retention, such as duration, location and assigned responsibility.*

State regulatory agencies and the U.S. Nuclear Regulatory Commission have applied the ASME Boiler and Pressure Vessel Code to welding activities involving pressure boundary parts, components and systems. This Code requires the development of quality assurance policies and procedures which delineate, among other things, the records to be employed for welding activities. It also specifies certain specific welding records which must be included. Many of these same specific welding records are also required by AWS Structural Welding Code. Therefore, requirements for welding records are contained in two documents:

- Company Quality Assurance Manual
- Applicable Welding Code

Scope of Required Records

Welding records include documents, procedures, and record forms. In general, documents specify requirements to be met by welding operations; procedures describe responsibilities, duties, and methods of accomplishing welding operations; both procedures and record forms provide evidence of how welding operations were performed; and record forms attest to the quality of welds and qualification of procedures and personnel. These records are listed in Table 28-10-1.

TABLE 28-10-1, WELDING RECORDS

RECORD	TYPE(1)	PURPOSE WITH RESPECT TO WELDING
Design or Installation Specification	D	Specifies Applicable Welding Code and Materials
Design or Installation Drawings	D	Specifies Weld Joint Types and Unique Welding Requirements
Detail Manufacturing or Installation Drawings	D	Specifies Weld Joint Preparation and Unique Welding Requirements
Welding Procedure Specification (WPS)	P	Describes How Welding is to be Accomplished
Heat Treatment Procedure	P	Describes How Post Weld Heat Treatment is to be Accomplished
Nondestructive Examination Procedures (RT, MT, PT, UT)	P	Describes How Nondestructive Examinations are to be Accomplished
Sequential Manufacturing or Installation Instructions (Job Package)(2)	P	Describes the Specific Procedures and Records Applicable to Specific Weld Joints
Procedure Qualification Record (PQR)	R	Provides Evidence of Satisfactory Qualification of Welding Procedure Specifications
Welder and Welding Operator Performance Qualification Record	R	Provides Evidence of Satisfactory Welder Qualification
Nondestructive Examination Personnel Certification Record	R	Provide Evidence of Satisfactory NDE Personnel Qualification
Certified Material Test Report	R	Provides Evidence of Acceptable Filler Material
Welder and Welding Operator Stamps or Weld Joint Record(3)	R	Provides Evidence of Who Made the Weld

TABLE 28-10-1, WELDING RECORDS (continued)

RECORD	TYPE(1)	PURPOSE WITH RESPECT TO WELDING
NDE Inspection Reports	R	Provides Evidence of Examination and Acceptance of the Weld and by Whom
Other Procedures and Records	P,R	Describe Responsibilities and Duties for Carrying Out Welding Operations; Provides Evidence of Implementation of Such Responsibilities and Duties, Including Monitoring Monitoring and Auditing Activities

Notes: (1) Type: D = Document, P = Procedure, R = Record Form

(2) Sequential manufacturing or installation instructions may not be classified as a record if a weld joint history record is used and contains sufficient entries to identify the WPS, the welder, heat treat procedure and NDE procedure.

(3) Weld joint history records may not be used if the "job package" is treated as a record and the weld is stamped by the welder and NDE personnel.

END

QUALITY CHARACTERISTICS OF RECORDS

Quality of records pertains to the time period of record generation and use and to the time period of record storage for historical purposes. Only the first time period is of concern at this point since record storage systems are beyond the scope of this module.

Welding records have satisfactory quality if they are identifiable, legible, and complete. Factors involved with each of these characteristics are described as follows:

- Identifiable. Identification of records is always in terms of the item represented by the record. The record identifies which product or person is governed or represented by the record. Documents and Procedures exhibit this characteristic by their title, statement of scope or purpose, identification number and revision number. Such identification associates the document or procedure with the type of product or population of people but not necessarily with a given unit of that type or specific individual within the population. For example, "Design Specification for Main Coolant Pumps, MCP-1, Revision 1," identifies the type of pump being governed by the document but does not identify each pump of that type. Instead, the document applies to all pumps of that type. Record forms are identifiable not only to types but also to specific entities within a type. Unit identification is provided by heat, lot, or control number; part number; part serial number; component serial number; system identification number; and personnel identification name or number. Examples of each are as follows:

- Heat, Lot, or Control Number - is entered on records which represent materials. Example: The Certified Material Test Report and the receiving inspection record for a given classification of filler material are identifiable to the product by heat, lot, or control number of the material.
- Part Number - is entered along with a lot number or quantity on records which represent parts and subassemblies. Example: Records of a weld repair of a part are identifiable to the product by part number.
- Part Serial Number - is entered along with part number on records which represent serialized parts and subassemblies. Applicable technical specifications require serialization of parts and subassemblies when each individual unit must be traceable to all processing steps. Example: Records of a weld repair of a serialized part are identifiable to the product by part number and serial number.
- Component Serial Number - is entered along with component name and weld joint identification on records which represent the specific component. Example: Radiographic examination for reactor vessel serial number A-106 inlet nozzle B to elliptical head weld is identifiable to the product by the component serial number.
- System Identification Number - is entered along with component serial numbers and weld joint identification on records which represent system installation, modification, or repair. Example: Radiographic examination report for system CWS-1, pipe to pump nozzle weld joint, is identifiable to the product by the same number.

  - Personnel Identification - is entered on all records. If the record represents product, the person's name or number represents who performed the activity on the product. If the record represents people, both the person represented and the person making the entries are recorded. Example: Personnel qualification record for employee granted by employee B is identifiable by names or numbers to both persons.
- Legible - Legibility provides for readability and understanding. Factors which provide for legibility are:
  - Neatness - Not only legible entries but also placement of the entries is important, i.e., can the entry be read in association with its purpose?
  - Control of Corrections - Erroneous entries invariably occur from time to time. Their correction either degrades or maintains legibility of the record. The best practice is to prohibit erasures and to require a single line through the erroneous data, entry of correct data, and initial of the person making the correction.
- Complete - Completeness means entry of all required data and entries in every block of record forms. It supports accuracy and validity of records. For each type of record, it is best to have a procedure which identifies the minimum required data entries. A typical procedure requires entry of product identifiers, results of the activity represented by the record, acceptance or rejection of such results, identification of person(s) performing the activity and completing the record, and date. Record forms are frequently planned to be useable for various, similar

activities. For this reason, some portions of a form may not require data entries for a given activity. In such instances, it is best to require entry of "not applicable" to avoid the appearance of an incomplete record.

SPECIFIC RECORDS

Other modules of this course describe the documents and procedures which also serve as welding records. Therefore, this section is limited to specific welding record forms which are required by the ASME Boiler and Pressure Vessel Code (referred to hereafter as the Code). These record forms are those listed previously in Table 28-10-1.

Procedure Qualification Record

As described by Module 28-5, welding procedure specifications (WPS) are prepared and qualified for each welding process and "set" of essential variables. Documentation of the qualification of a WPS is on the Procedure Qualification Record (PQR).

Every WPS is supported by a PQR although a given PQR may suffice for more than one WPS. When two or more WPS exist for the same welding process, only one PQR is necessary if the differences among the procedures do not involve different essential variables. For this reason, most companies maintain a supplementary record which lists each WPS number and its supporting PQR number. This listing is useful in preparing processing instructions for a particular job because it provides evidence that the WPS intended for use on the job either is or is not already qualified.

Each PQR is assigned a unique serial number which permits easy identification and retrieval of the record. The

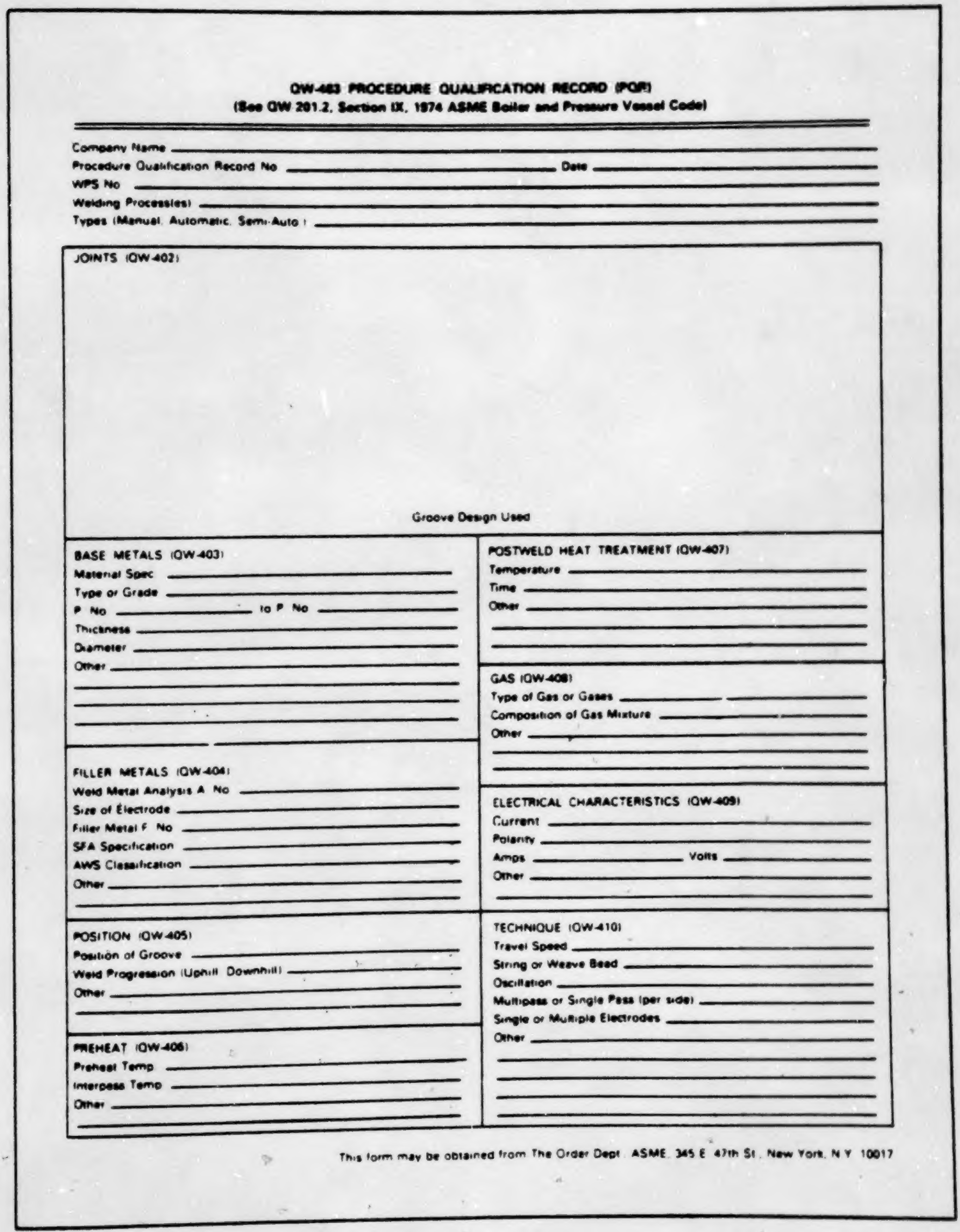
PQR also contains entry of each WPS number supported by the PQR. Since each WPS bears the serial number of its supporting PQR, a complete cross reference is maintained between procedure and its qualification record.

Entries on the PQR represent the actual data for welding a qualification test piece, examining and testing the test piece, and accepting the results of examinations and tests. The entries may be made directly on the PQR by the persons performing each activity or a designated person may make all the entries by transposing values from other supporting records. In the latter instance, the separate supporting records consist of welding data reports, nondestructive examination reports, and destructive test reports. Such individual records are forwarded to the designated person who prepares the PQR. This approach is typically used by companies having large numbers of on-going qualifications.

The Nuclear QA/QC Technician may be assigned any of the following task with respect to the PQR:

- Observe the qualification welding and make all welding data entries.
- Review PQR for completeness and compliance with the Code.
- Prepare and maintain a listing which cross references each WPS with its PQR.
- Monitor or audit the PQR program.
- Monitor or audit welding operators to determine that a WPS in use is supported by a proper PQR.

The PQR format recommended by the Code is shown in Figure 28-10-1 on the next two pages.



QW-483 PROCEDURE QUALIFICATION RECORD (PQR)
(See QW 201.2, Section IX, 1974 ASME Boiler and Pressure Vessel Code)

Company Name ______
Procedure Qualification Record No ______ Date ______
WPS No ______
Welding Process(es) ______
Types (Manual, Automatic, Semi-Auto.) ______

JOINTS (QW-402)

Groove Design Used

BASE METALS (QW-403)
Material Spec ______
Type or Grade ______
P No ______ to P No ______
Thickness ______
Diameter ______
Other ______

FILLER METALS (QW-404)
Weld Metal Analysis A No ______
Size of Electrode ______
Filler Metal F No ______
SFA Specification ______
AWS Classification ______
Other ______

POSITION (QW-405)
Position of Groove ______
Weld Progression (Uphill, Downhill) ______
Other ______

PREHEAT (QW-406)
Preheat Temp ______
Interpass Temp ______
Other ______

POSTWELD HEAT TREATMENT (QW-407)
Temperature ______
Time ______
Other ______

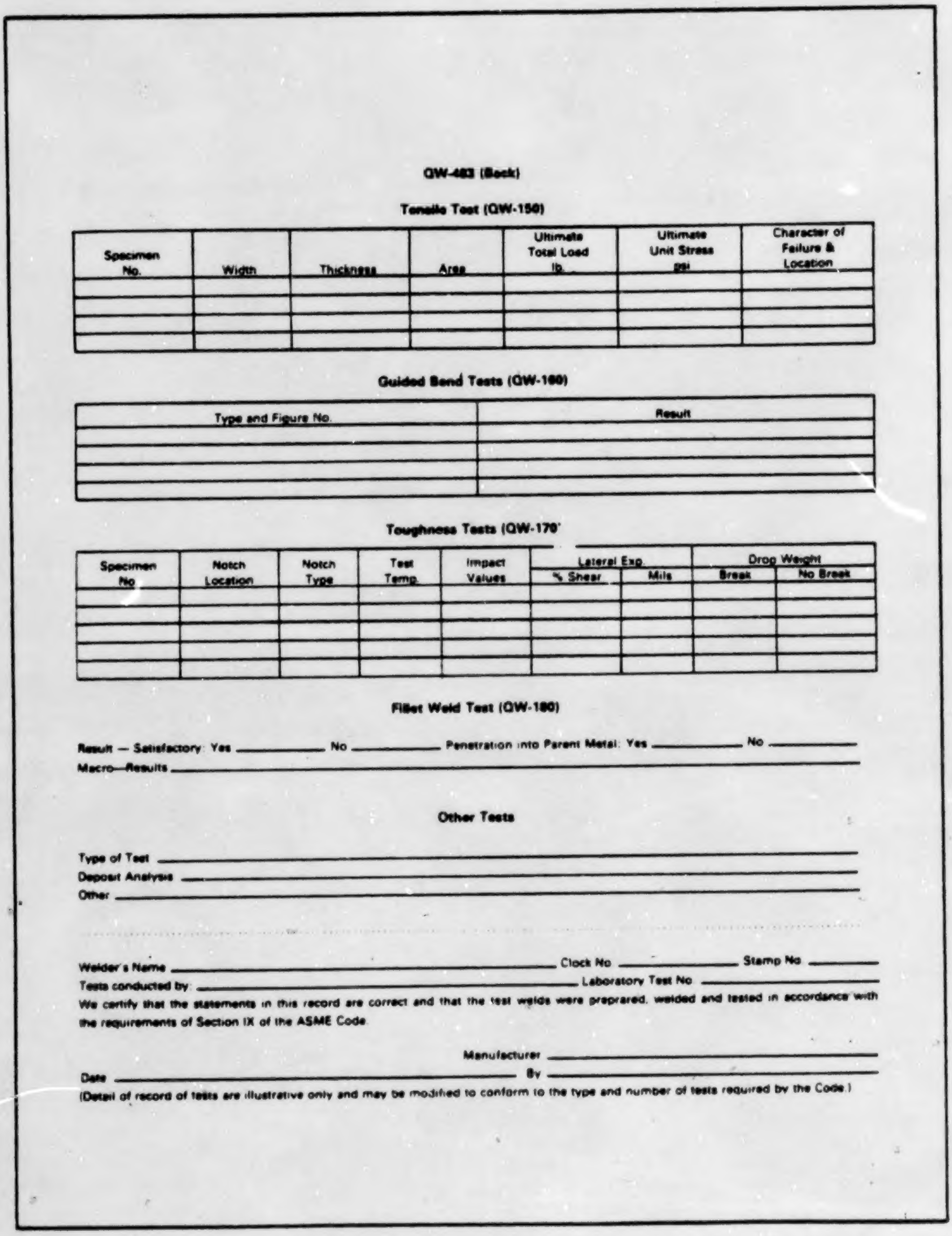
GAS (QW-408)
Type of Gas or Gases ______ ______
Composition of Gas Mixture ______
Other ______

ELECTRICAL CHARACTERISTICS (QW-409)
Current ______
Polarity ______
Amps ______ Volts ______
Other ______

TECHNIQUE (QW-410)
Travel Speed ______
String or Weave Bead ______
Oscillation ______
Multipass or Single Pass (per side) ______
Single or Multiple Electrodes ______
Other ______

This form may be obtained from The Order Dept., ASME, 345 E. 47th St., New York, N.Y. 10017

Figure 28-10-1 PQR Format - Page 1 of 2



QW-483 (Back)

Tensile Test (QW-150)

Specimen No.	Width	Thickness	Area	Ultimate Total Load lb.	Ultimate Unit Stress psi	Character of Failure & Location

Guided Bend Tests (QW-160)

Type and Figure No.	Result

Toughness Tests (QW-170)

Specimen No	Notch Location	Notch Type	Test Temp.	Impact Values	Lateral Exp.		Drop Weight	
					% Shear	Mils	Break	No Break

Fillet Weld Test (QW-180)

Result — Satisfactory: Yes ____________ No ____________ Penetration into Parent Metal: Yes ____________ No ____________
Macro—Results ____

Other Tests

Type of Test ____
Deposit Analysis ____
Other ____

Welder's Name ______________________________ Clock No ____________ Stamp No ____________
Tests conducted by: ______________________________ Laboratory Test No ____________

We certify that the statements in this record are correct and that the test welds were preprared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

Manufacturer ______________________________
Date ______________________________ By ______________________________

(Detail of record of tests are illustrative only and may be modified to conform to the type and number of tests required by the Code.)

Figure 28-10-1 PQR Format - Page 2 of 2

Welder and Welding Operator Performance Qualification Record

As described by Module 28-5, each welder and welding operator must be qualified. Documentation of their qualification is on the Welder and Welding Operator Performance Qualification Record. The qualifications are categorized as welder or welding operator dependent on the duties of the individual which are defined as follows:

- **Welder** - One who is capable of performing a manual or semi-automatic welding operation.
- **Welding Operator** - One who operates machine or automatic welding equipment.

As indicated by the above definitions, a welder is responsible for making necessary adjustment in welding parameters to maintain proper welding while welding operations are underway. Conversely, a welding operator sets up the equipment, starts and stops it, but makes no adjustments while welding is underway. Accordingly, more stringent requirements apply to qualification of the welder. However, the same record form is suitable for either.

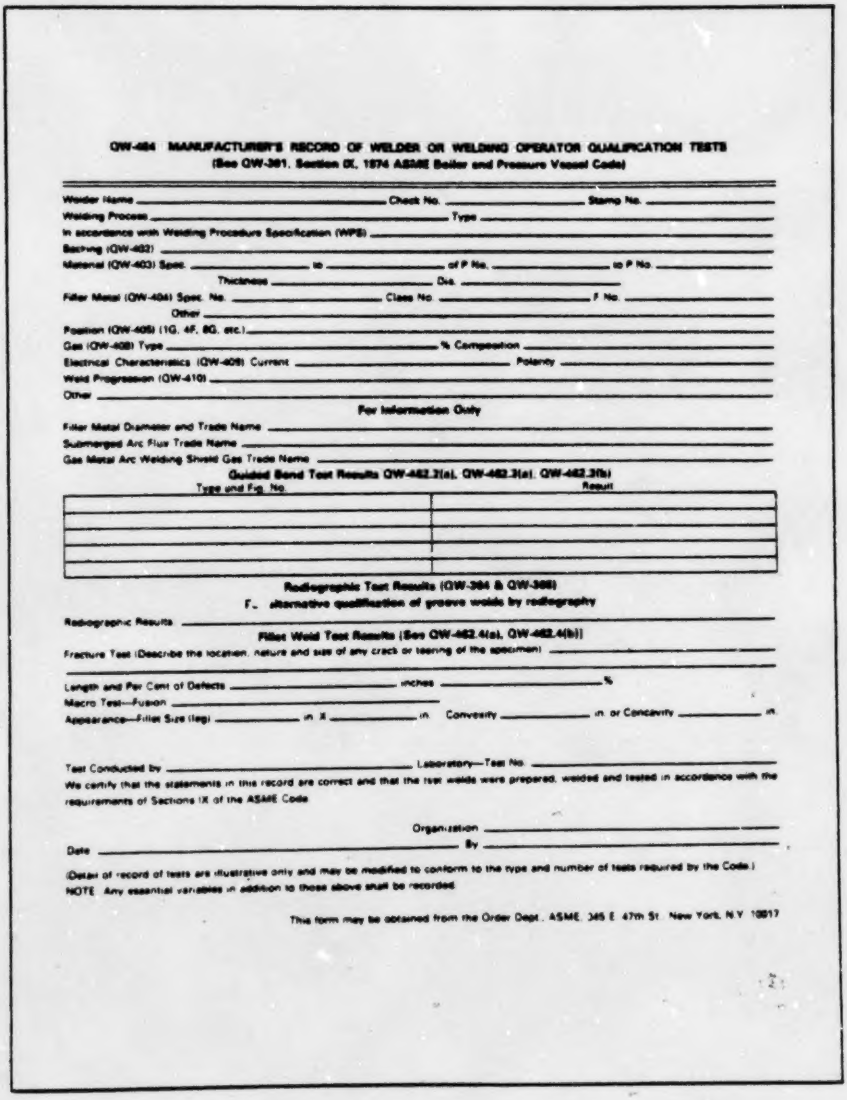
Each qualified welder and welding operator is assigned a unique number, letter, or symbol which is used to identify the work by that person. The assigned identifier is entered on the person's qualification record. Also, the welding process and the WPS number is entered. These three entries permit cross-reference from work records to individual qualification records.

The Nuclear QA/QC Technician may be assigned any of the following tasks with respect to the Welder and Welding Operator Performance Qualification Record:

- Monitor qualification welding and enter welding data on the record.
- Monitor or audit the conduct of the qualification program including generation of the record.

- Monitor or audit welding operations to determine that each welder and welding operator is properly qualified.

The format suggested by the Code for this record is shown in Figure 28-10-2.



QW-484 MANUFACTURER'S RECORD OF WELDER OR WELDING OPERATOR QUALIFICATION TESTS
(See QW-301, Section IX, 1974 ASME Boiler and Pressure Vessel Code)

Welder Name ____ Check No. ____ Stamp No. ____
Welding Process ____ Type ____
In accordance with Welding Procedure Specification (WPS) ____
Backing (QW-402) ____
Material (QW-403) Spec. ____ to ____ of P No. ____ to P No. ____
Thickness ____ Dia. ____
Filler Metal (QW-404) Spec. No. ____ Class No. ____ F No. ____
Other ____
Position (QW-405) (1G, 4F, 6G, etc.) ____
Gas (QW-408) Type ____ % Composition ____
Electrical Characteristics (QW-409) Current ____ Polarity ____
Weld Progression (QW-410) ____
Other ____

For Information Only

Filler Metal Diameter and Trade Name ____
Submerged Arc Flux Trade Name ____
Gas Metal Arc Welding Shield Gas Trade Name ____

Guided Bend Test Results QW-462.2(a), QW-462.3(a), QW-462.3(b)

Type and Fig. No.	Result

Radiographic Test Results (QW-304 & QW-305)
F. alternative qualification of groove welds by radiography

Radiographic Results ____

Fillet Weld Test Results (See QW-462.4(a), QW-462.4(b))

Fracture Test (Describe the location, nature and size of any crack or tearing of the specimen) ____
Length and Per Cent of Defects ____ inches ____ %
Macro Test—Fusion ____
Appearance—Fillet Size (leg) ____ in. X ____ in. Convexity ____ in. or Concavity ____ in.

Test Conducted by ____ Laboratory—Test No. ____

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Sections IX of the ASME Code

Organization ____
Date ____ By ____

(Detail of record of tests are illustrative only and may be modified to conform to the type and number of tests required by the Code.)
NOTE: Any essential variables in addition to those above shall be recorded.

This form may be obtained from the Order Dept., ASME, 345 E. 47th St., New York, N.Y. 10017

Figure 28-10-2 Welder & Welding Operator Performance Qualification Record Information

Nondestructive Examination Procedure Demonstration Record

Code work is subject to inspection by the Authorized Inspector. The Authorized Inspector is employed by an agency authorized by the state to enforce compliance with the Code. With regard to nondestrucrive examination (NDE) procedures, the Code stipulates requirements to be met by NDE procedures and requires demonstration of their use to the satisfaction of the Authorized Inspector. An approval signature block on the procedure constitutes the demonstration record once it has been signed by the Authorized Inspector.

Each NDE procedure is identifiable by number and revision. For example, MT-3.02, Revision 2, identifies a specific magnetic particle examination procedure.

The Nuclear QA/QC Technician may be assigned either of the following tasks with respect to the NDE procedure demonstration record:

- Coordinate company actions with the Authorized Inspector to arrange for demonstrations and obtaining approval signature by the Authorized Inspector.
- Monitor or audit NDE activities to confirm that only NDE procedures which have been signed by the Authorized Inspector are in use.

Nondestructive Examination Personnel Certification Record

Each person who performs NDE activities is required to be qualified. Three qualification levels are established as follows:

- NDE Level I - An NDE Level I individual is qualified to properly perform specific evaluations according to written instructions and to record the results.

- NDE Level II - An NDE Level II individual is qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards, and specifications. He or she must be thoroughly familiar with the scope and limitations of the method and shall exercise assigned responsibility for on-the-job training and guidance of trainees and NDE Level I personnel. He or she shall be responsible for the training and examination of NDE Level I and Level II personnel for certification.
- NDE Level III - An NDE Level III individual shall be capable of and responsible for establishing techniques; interpreting codes, standards and specifications; and designating the particular test method and technique to be used. He or she is responsible for the training and examination of NDE Level I and Level II personnel for certification.

The certification record for each level of qualification is typically comprised of a number of individual records. The records are identifiable by the person's name or assigned number, letter or symbol. While there is no special format for any of the records, the certification records must collectively contain the following:

- Name of certified individual.
- Level of certification and test method.
- Educational background and experience of certified individuals.
- Statement indicating satisfactory completion of training in accordance with the employer's written procedure.
- Results of the prescribed physical examination.

- Copies of current examinations and of grades for all previous examinations and descriptions of practical test objects.
- Percentile weights assigned to each examination if examinations were employed for qualification.
- Composite grade if examinations were employed.
- Date of certification and/or recertification and the dates of hire or assignment to NDE.
- Signature of certifying agency representative.

The Nuclear QA/QC Technician may be assigned either of the following tasks with respect to NDE personnel certification records:

- Monitor or audit the administration of the certification program.
- Monitor or audit NDE activities to confirm that NDE personnel are properly qualified to the correct level.

Certified Material Test Report

As described by Module 28-8, each lot or heat of filler material is certified by the supplier as meeting the requirements of the applicable material specification. The Code requires certification by a Certified Material Test Report which not only states that the material confirms with requirements but also gives values for the results of acceptance testing. Each report is identifiable by lot or heat number of the material represented.

The Nuclear QA/QC Technician may be assigned either of the following tasks with respect to Certified Material Test Reports:

- Review the reports to determine compliance with purchase order and material specification requirements.

- Participate in audits of the material supplier to determine that reports are supported by supplier practices.

Welder and Welding Operator Stamps or Weld Joint Record

As described in the foregoing section on welder and welding operator performance qualification records, each qualified welder and welding operator is assigned a unique identifying number, letter, or symbol. The code requires traceability from a weld joint to the welder or welding operator who made the weld by one of the following methods:

- Physical application of the welder's or welding operator's identification mark on or adjacent to the weld made by him or her. Such marking must be along the entire weld length at intervals of three feet or less. Blunt die stamps are typically used for this purpose.
- Preparation of a weld joint record which correlates each weld joint with the welder or welding operator who made the weld. This option may be employed for all welds or it may be used only for those welds where stamping is impractical.

When physical marking of the weld is employed, the person's assigned number, letter or symbol identifies who made the weld. As previously described, that person's qualification records are also identifiable by the assigned number, letter or symbol. However, another record is necessary to identify which WPS was used to make the weld. The "job package" instructions typically constitute this additional record.

When weld joint records are employed, the record is identifiable by entries for (a) system or component name or number and, (b) weld joint name or number. The record identifies the WPS number and the welder or welding operator to indicate how the weld was made and by whom. A sample weld joint record is illustrated in Figure 28-10-3, courtesty of Niagara Mohawk Power Corporation.

The Nuclear QA/QC Technician may be assigned any of the following tasks with respect to welder and welding operator stamps and weld joint records:

- Monitor welding operations to confirm proper application to stamps or completion of weld joint records.
- Prepare weld joint records.
- Trace welders and welding operators identifying marks to corresponding qualification records to confirm use of qualified welders and welding operators.

NDE Inspection Reports

NDE inspection reports document the examination and acceptance of welds.

Except for radiography, special records formats are not typically used. Records of PT, MT, or UT examination typically consist of entries on other existing records such as the sequential processing instructions (job package), the weld joint record, or an inspection check list. Nonetheless, some companies use special formats for each of these NDE methods.

Radiography typically employs a special format even when entries are also made on sequential processing instructions or weld joint records. Unlike the other NDE methods whose results are interpreted as an integral step of conducting the NDE, the results of RT are not available until development and interpretation of the film. Therefore, an interpretation report serves to positively document the results of RT examination.

Regardless of format, each NDE record is identifiable to the weld, procedure and personnel by the following entries:

WELD HISTORY RECORD
NINE MILE POINT NUCLEAR STATION - UNIT 1

NAME OF SYSTEM ______________________ SYSTEM NO. __________
DRAWING NO. ______________________ WELD NO. __________
ISOMETRIC NO. ______________________ INDEX NO. __________

WELD DATA (ROOT)	FIT UP (1)		
	METHOD & PROCEDURE NO.		
	PREHEAT TEMPERATURE		
	SHIELD PURGE		
	BACK PURGE		
	AMPERAGE		
	POLARITY (2)		
	FILLER MATERIAL		
	WELDER'S INITIALS & NO.		
	TEST (3)		
	INSPECTOR'S SIGNATURE		DATE:
WELD DATA (INTERMEDIATE & FINAL)	METHOD & PROCEDURE NO.		
	PREHEAT TEMPERATURE		
	INTERPASS TEMPERATURE		
	SHIELD PURGE		
	AMPERAGE		
	POLARITY (2)		
	FILLER MATERIAL		
	WELDER'S INITIALS & NO.		
	TEST (3)		
	INSPECTOR'S SIGNATURE		DATE:

FABRICATION PIECE NO. __________ TO FABRICATION PIECE NO. __________
PIPE SIZE (NOMINAL) __________ TO PIPE SIZE (NOMINAL) __________
PIPE SCHEDULE __________ TO PIPE SCHEDULE __________
ASTM __________ TO ASTM __________

(1) Type A-Butt
B-Insert
C-Socket
D-Other (Name)

(2) Type A-DC Straight
B-DC Reverse
C-AC

(3) Type A-Visual
B-PT Dye Penetrant
C-MT Magnetic Particle
D-RT Radiograph
E-UT Ultrasonic

Figure 28-10-3 Sample Weld Joint Record

- System or component name or number
- Weld joint name or number
- NDE procedure number (for each method of NDE used)
- NDE person's name or identifiable number, letter or symbol (for each person conducting NDE and interpreting results thereof)

Sample RT interpretation reports are illustrated in Figures 28-10-4 and 28-10-5, courtesy of Niagara Mohawk Power Corporation and Industrial Testing Laboratory Services Corporation. Comparison of these formats reveals that the utility format identifies the RT procedure number while the test laboratory format has provision for listing all essential variables used in performing the RT. The testing laboratory format permits client approval of the RT procedure by approving the interpretation report, and thus, avoiding time delays for procedure approvals.

The Nuclear QA/QC Technician may be assigned any of the following tasks with respect to NDE records:

- Assist in developing NDE record's format and instruction for their use.
- Monitor or audit NDE activities to confirm proper completion of NDE records.
- Collect NDE reports, tabulate data, and analyze the data for trends in weld defect rates.

NIAGARA MOHAWK POWER CORPORATION
NMP-JAF NUCLEAR SITE
RADIOGRAPHIC INTERPRETATION REPORT

QCIR-77-679
NDE 5.00
CN Orig.
March 1977

Component or System CONTROL ROD DRIVE - 44.1	ISO/Drawing/Weld Map	Weld No. SEE BELOW	Date
Supplier GE	Code Section ASME VIII ___ ASME III ✓ B-31 ___ Other ___	Joint Design Backing Ring ___ Insert ___ Open ✓ Mat'l S/S	Job No.
Stage of Mfg. COMPLETED			Radiographic Procedure(s) N10
Radiographed By: (Co.) MTL			Casting ___ Weldment ✓ Other ___

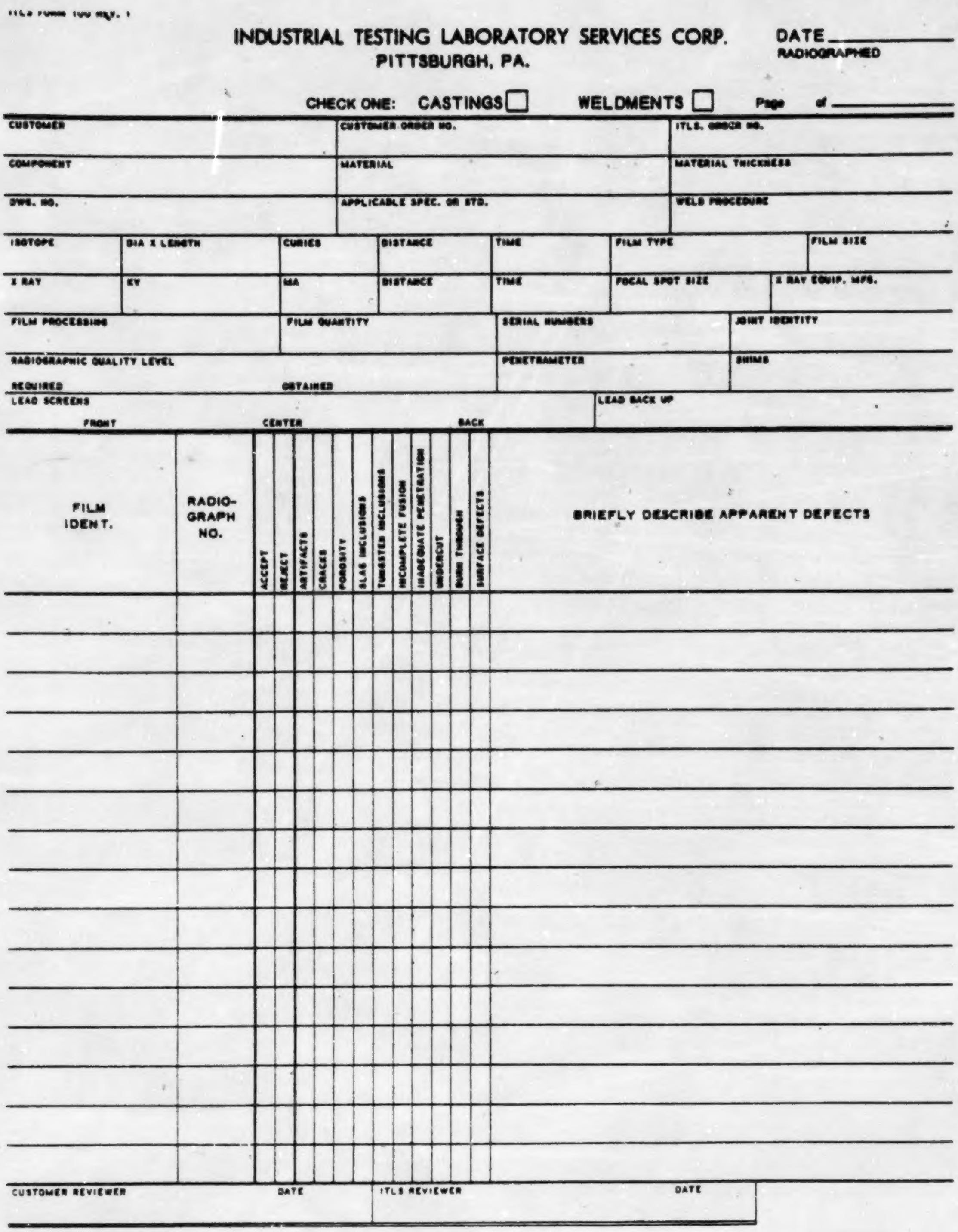
	Station Nos.	Accept	Reject	Root Concavity	Root Convexity	Cracks	Slag Incl.	Tungsten	Porosity	Incomp. Penet.	Incomp. Fusion	Undercut	Burn-Thru	Oxidation	Surface Defects	Remarks
FW P44.1-16C	WELD #1															6-13-77
	0-1	✓														2.36 2.64
	1-2	✓							✓							FILM ARTIFACTS SCRATCHES
	2-3	✓														
	3-0	✓														FILM ARTIFACTS SCRATCHES
FW P44.1-16D	WELD #2															
	0-1	✓														FILM ARTIFACT / FILM ONLY
	1-2	✓														FILM ARTIFACTS
	2-3	✓														NEAR 2 CHECK FOR MIN. WALL
	3-0	✓														2-3 NO PROBLEM FILM CRIMPED
FW P44.1-16E	WELD #3															3-0 FILM ARTIFACTS
	0-1	✓							✓							
	1-2	✓							✓							
	2-3	✓							✓							
	3-0	✓														
FW P44.1-16-F	WELD #4															
	0-1	✓														
	1-2	✓		✓												ACCEPTABLE
	2-3	✓		✓												
	3-0	✓														
FW P-44.1-16B	WELD #6															
	0-1		✓							✓	✓					6-13-77
	1-2	✓		✓												ACCEPTABLE
	2-3	✓														
	3-0	✓														SAME DEFECT 0-1

Gary Leskiw
Interpretation By:

III
NDE Level

6-13-77
Date

Figure 28-10-4 Radiographic Interpretation Report



ITLS FORM 100 REV. 1

INDUSTRIAL TESTING LABORATORY SERVICES CORP.
PITTSBURGH, PA.

DATE RADIOGRAPHED ____________

CHECK ONE: CASTINGS ☐ WELDMENTS ☐ Page ____ of ____

CUSTOMER	CUSTOMER ORDER NO.	ITLS. ORDER NO.
COMPONENT	MATERIAL	MATERIAL THICKNESS
DWG. NO.	APPLICABLE SPEC. OR STD.	WELD PROCEDURE

ISOTOPE	DIA X LENGTH	CURIES	DISTANCE	TIME	FILM TYPE	FILM SIZE
X RAY	KV	MA	DISTANCE	TIME	FOCAL SPOT SIZE	X RAY EQUIP. MFG.

FILM PROCESSING	FILM QUANTITY	SERIAL NUMBERS	JOINT IDENTITY
RADIOGRAPHIC QUALITY LEVEL REQUIRED OBTAINED		PENETRAMETER	SHIMS
LEAD SCREENS FRONT CENTER BACK		LEAD BACK UP	

FILM IDENT.	RADIOGRAPH NO.	ACCEPT	REJECT	ARTIFACTS	CRACKS	POROSITY	SLAG INCLUSIONS	TUNGSTEN INCLUSIONS	INCOMPLETE FUSION	INADEQUATE PENETRATION	UNDERCUT	BURN THROUGH	SURFACE DEFECTS	BRIEFLY DESCRIBE APPARENT DEFECTS

CUSTOMER REVIEWER	DATE	ITLS REVIEWER	DATE

Figure 28-10-5 Sample RT Interpretation Record

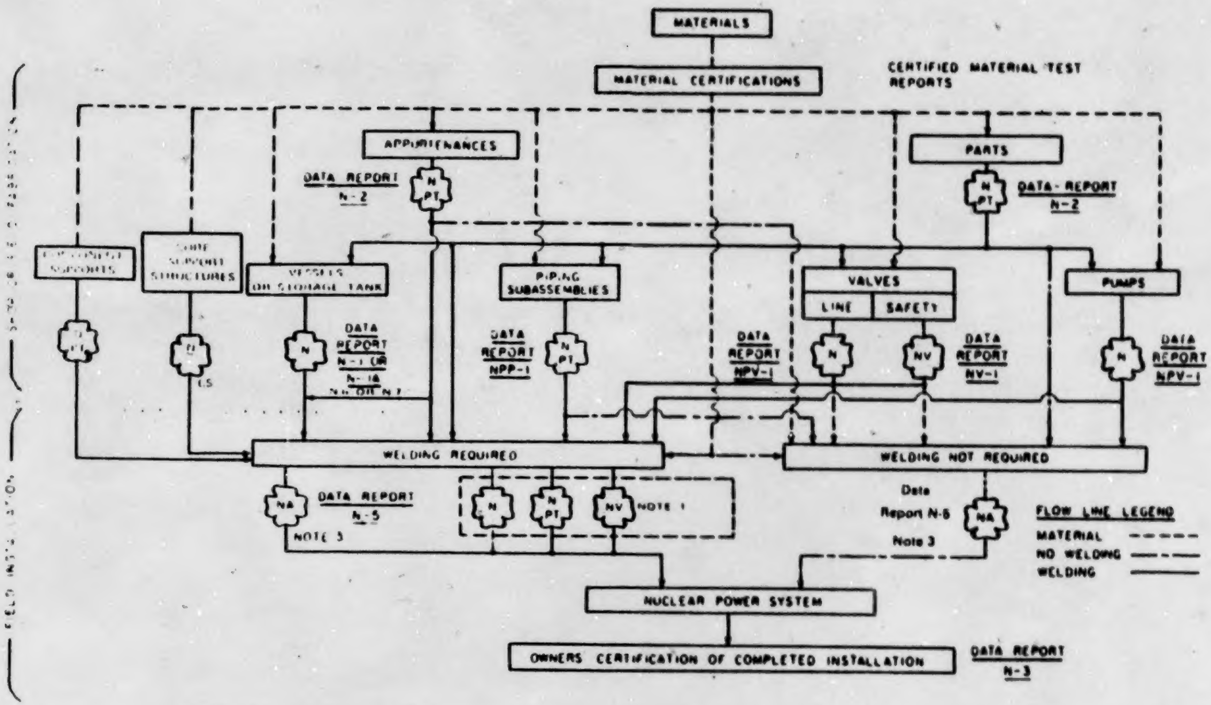
PRODUCT CERTIFICATION

The ASME Boiler and Pressure Vessel Code requires certification of compliance with the Code for all work governed by the Code. A scheme of data reports is established for this purpose such that no matter how many contractors and subcontractors are involved, data reports flow with product movement until the owner of the nuclear power plant possesses all data reports. This scheme is illustrated in Figure 28-10-6 on the following page.

Certain welding records are always attached to any of the data reports listed in Figure 28-10-6. These are:

- Certified material test reports
- Nondestructive examination reports
- Actual radiographs where RT is performed
- Heat treatment records

The data reports and attached records are retained by the owner of the nuclear power plant or agent thereof, for the operational life of the product represented. Other welding records are retained by each company for a time period stipulated by the contractor for the product or services. A typical retention period is for two years after initial startup and operation of the nuclear power plant. Records generated during the operation of the plant are retained from one year to the life of the product dependent on the type of record.


MATERIALS
MATERIAL CERTIFICATIONS
CERTIFIED MATERIAL TEST REPORTS
APPURTENANCES
DATA REPORT N-2
N PT
PARTS
DATA-REPORT N-2
COMPONENT SUPPORTS
CORE SUPPORT STRUCTURES
VESSELS OR STORAGE TANK
PIPING SUBASSEMBLIES
VALVES
LINE
SAFETY
PUMPS
CS
N
DATA REPORT N-1 OR N-1A N-… OR N-2
DATA REPORT NPP-1
DATA REPORT NPV-1
NV
DATA REPORT NV-1
DATA REPORT NPV-1
WELDING REQUIRED
WELDING NOT REQUIRED
NA
DATA REPORT N-5
NOTE 3
NOTE 1
Data Report N-5
Note 3
FLOW LINE LEGEND
MATERIAL - - - - -
NO WELDING — - —
WELDING ———
NUCLEAR POWER SYSTEM
OWNERS CERTIFICATION OF COMPLETED INSTALLATION
DATA REPORT N-3

NOTES

1. Applicable only when Certificate Holder's authorization includes extension to field operations for completion or repair of items constructed in his own shop or field location [Table NA-8210-1, Note (2)]. In this case, the Data Report form applicable to the items may be used in place of Form N-5 (Appendix V).
2. The class of construction (1, 2, 3, CS, or MC) shall be indicated by the numeral 1, 2, or 3 or the letters CS or MC stamped below and outside the Official Code symbol.
3. Field installation of items requires Authorization and application of the NA symbol stamp.

Figure 28-10-6 Material Certification, Code N-Type Symbol, and Data Reports for Nuclear Power and Containment Systems (Class 1,2,3,CS, and MC) (Note 2)

EXERCISES

The following exercises serve to reinforce the information presented in this module. Answer each question based upon the material presented.

1. Discuss briefly why welding records need to be maintained and what document(s) stipulate that they need to be maintained and controlled.

2. What conditions are needed for a record to be of satisfactory quality?

3. Briefly explain the purpose(s) of each of the following:
    a. Documents
    b. Procedures
    c. Record forms

4. Given any of the following records, state its purpose and describe how it is identifiable:
    a. Procedure Qualification Records
    b. Welder and Welding Operator Performance Qualification Record
    c. Nondestructive Examination Procedure Demonstration Record
    d. Nondestructive Examination Personnel Certification Record
    e. Certified Material Test Report
    f. Weld Joint Record
    g. Nondestructive Examination Reprot

5. Given any of the records listed in #4 above, state two tasks which may be assigned to the Nuclear QA/QC Technician with respect to the record.

MATERIALS

None.

PROCEDURES

None.

DATA TABLE

None.

REFERENCE MATERIALS

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, V and IX, ASME, New York, New York

American Society for Nondestructive Testing, SNT-TC-1A Recommended Practices for NDE Personnel Qualifications, ASNT, Evanston, Illinois 60202

TEST

1. Matching - Match the following statements.

____ a. Quality Assurance Manual
____ b. Welding records
____ c. Welding Documents
____ d. Welding Procedures
____ e. Procedure Qualification Records (PQR)
____ f. NDE personnel certification records
____ g. Certified Material Test Reports
____ h. Welder and Welding Operator

(1) serve to identify who made the weld.
(2) describe responsibilities, duties, and methods of accomplishing welding activities.
(3) serve to document the qualification of Welding Procedure Specifications (WPS).
(4) document the level of qualification achieved by a person.
(5) specify requirements to be met and include design or installation specifications and drawings.
(6) this along with the applicable welding code stipulate what welding records need to be maintained.
(7) includes documents, procedures and record forms.
(8) attest to the quality of filler material and report actual results of acceptance testing.

2. Name three characteristics of records which represent record quality and discuss each in terms of factors which contribute to record quality.

3. A record is considered complete if all required entries are made. List three items which should be included in a record.

4. True - False - Place a T or F in front of the following statements denoting whether they are true or false.

____ a. Welding records include documents, procedures and record forms.

____ b. Procedures attest to the quality of welds and qualification of personnel.

____ c. A record is complete if all required entries have been made.

____ d. A PQR is identifiable by its assigned unique serial number and its cross-reference with the (WPS).

____ e. The nuclear QA/QC technician may monitor or audit the welder qualification program and monitor or audit activities to confirm use of qualified welders and welding operators.

____ f. NDE personnel certification records document the level of qualification achieved by a person.

____ g. The nuclear QA/QC technician may review Certified Material Test Reports for acceptance and participate in audits of the material supplier.

____ h. NDE inspection reports serve to identify the person who made the weld.

____ i. Welding records which are forwarded with certified data reports to the owner are:
- certified material test reports
- nondestructive examination reports
- actual radiographs where RT is performed
- heat treatment records

NUCLEAR TECHNOLOGY

INDEX

COURSE 28 - WELDING INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

4800 LAKEWOOD DRIVE WACO, TEXAS

NUCLEAR TECHNOLOGY SERIES
INDEX
for
COURSE 28, WELDING INSPECTION (TEN MODULES)

NOTE: Each module in this Course is numbered separately, and the page numbers begin with page 1 in each module. Therefore, this Index lists for each entry the module number (underlined), followed by a comma and the page number. Figures and tables are listed by their numbers, followed by the module and page number in parentheses. A Master Index is available in a separate volume. This general index merges all index entries from the 35 Nuclear Courses. It is a valuable research tool, with which the student or researcher can locate all the references to any subject within the 35 Courses.

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